Developing monitoring methods for cryptic species:

A case study of the Australasian bittern, *Botaurus poiciloptilus*.

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Abstract

Difficult-to-detect species (here-after, ‘cryptic’) are problematic to monitor. This is because sampling is often restricted by logistic complications, and species-detectability tends to be low and/or highly variable. Such challenges create data that are complex to interpret, and contain biases that cannot be estimated, making results less meaningful. Yet there is a need to monitor such species as they are also often rare.

In this thesis I review 30 publications, covering 28 different species, to demonstrate that challenges experienced across cryptic species fall into four categories: visually-cryptic, behaviourally-cryptic, spatially-cryptic and temporally-cryptic. The Australasian bittern (*Botaurus poiciloptilus*) is an appropriate case-study for examining the process of developing a monitoring method for cryptic threatened species because they have all four cryptic characteristics. Yet bitterns are also endangered, and what is left of their habitat is under-threat. Currently the most feasible monitoring method available for bitterns is counts of male calls (booms) during the breeding season. However, calling-rate is known to be variable and difficulties in accessing some sites restricts sampling possibilities.

I fitted a range of generalised linear mixed models to 461 15-min call-counts, conducted in a range of conditions, during two breeding seasons at Whangamarino wetland, to identify factors affecting calling-rate-per-individual-bittern (CRPI). Results showed that CRPI was predictable in terms of time-of-day, time-of-year, cloud-cover, rainfall and certain moon parameters, but some spatial and temporal variation remained unexplained. Additionally, I showed that recorders are a cost-effective practical solution to logistical constraints restricting sampling possibilities at some sites. Furthermore, I show that abundance can be estimated from calling-rate by correcting for effect sizes of factors affecting CRPI. Results obtained using 269 15-min sound-files at two sites (Whangamarino wetland and Lake Whatumā) show that these abundance derivations are accurate but imprecise. To understand more about how call-based methods can be used to monitor bitterns, I radio-tracked six males throughout the optimum monitoring-period to confirm that these birds have high site-fidelity, therefore, validating territory-mapping method assumptions. The approach used in this thesis is applicable to any cryptic species, as illustrated with the Guam rail (*Gallirallus owstoni*) in my final discussion.

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To Barry White,

for teaching me how to think like a male bittern, and showing me how to elicit the behaviour needed to catch your kind.

And

To Frank Sinatra,

for teaching me that no matter how hard I try I will never be able to catch all male bitterns. I'd like to think we caught you in 2015 but that's something that only you would know.

1

Chapter 1: Defining the cryptic conundrum

A cryptic spider, genus unk. (centre of photo). Credit: Piet Grobler, 2009.

1.1 Introduction

Management of threatened species is one of the major challenges faced by conservationists (Clarke *et al.*, 2003; MacKenzie & Nichols, 2004). Managers rely on monitoring to assess whether species' populations are declining, where declines are occurring, the rate of declines, and the response of populations to management practises (Kéry & Schmidt, 2008). Developing and applying monitoring methods can be problematic, even for the most perceptible of species. When the target species is cryptic, as in difficult to detect, these challenges are amplified (Clarke *et al.*, 2003). With cryptic species, data are often challenging to interpret, and contain biases and errors that frequently cannot be estimated, making results less meaningful (Clarke *et al.*, 2003). Yet the consequences of not monitoring these species are high. A threatened cryptic species will only get harder to monitor as it declines, and without the ability to identify the causes of decline, and how to reverse them, extinction can become inevitable.

In this Chapter, I cover five key topics. Firstly, I will describe the process of developing monitoring methods that is applicable to all wildlife species. Secondly, I will outline, using recent examples, some challenges experienced while applying this developmental process to cryptic wildlife species and some options available to solve these challenges. Thirdly, I will introduce characteristics of the Australasian bittern (*Botaurus poiciloptilus*) that make it an appropriate case study for developing monitoring methods for cryptic threatened species. In this section, I discuss knowledge gaps for this species, and the importance of developing a monitoring method to overcome these gaps. Fourthly, I will outline the aims of this thesis, providing details of how work presented in this thesis will help identify and address knowledge gaps currently constraining our ability to conserve this fascinating and under-publicised species. Finally I will summarise how this process could be used to help solve monitoring conundrums with other cryptic species.

1.2 The process of developing population monitoring programmes

Monitoring can be defined as 'a repeated assessment of the status of some quantity, attribute, or task within a defined area over a specified time period' (Thompson *et al.*, 1998). Specifically, in the context of this thesis, monitoring can also be expressed as observations or measures undertaken with the 'intent to assess change' (MacDonald *et al.*, 1991).

There are numerous approaches to monitoring wildlife populations, and the type of monitoring employed must be matched carefully with the aims and objectives of the study (MacDonald *et al.*, 1991). Reasons for monitoring are project specific, but can be simplified to three key points (Greene, 2012):

- 'To understand what we have got in our area of interest.
- To discover whether there has been any change in population size and, if so, what processes were driving that change.
- Determine the effectiveness of management actions and whether any changes to those actions affected population size'

The first of these is a static assessment of the population ('status') and involves working out what is present (or absent) and which sites are important for further investigation or protection. The second point is a dynamic assessment of the condition of a population ('trends'). It is the process of quantifying the extent and direction of the population change, i.e. understanding what the change is and which key factors are driving the change (e.g. threats or management practises). This stage is crucial for informed decision making, prioritisation and/or competition for conservation funds that are inevitably limited (Thompson *et al.*, 1998). The third point relates to reversing the causes of decline (assuming there is one), once the status and population trends are known. Caughley (1994) strongly advocates addressing the second and third points together using a hypothetico-deductive scientific process. That way, the process of removing or neutralising hypothesised threats individually, as a series of adaptive management experiments, provides confirmation that these threats have been identified correctly

(Lee, 1999). This ensures that no threats are missed throughout the recovery process. It also enables results to be fed back into to the monitoring process so that population status and trends can be updated and resources can be reprioritised.

According to Lindenmayer *et al.* (2012), an effective monitoring method should a) provide information on populations' changes (trends); b) act as an early warning system to prevent scenarios that may be expensive or impossible to reverse; c) enable managers to quantify conservation actions as successful or unsuccessful; d) enable managers to refine and improve techniques; and e) provide information regarding the extent of conservation in terms of the overall investment.

The process of developing a monitoring programme can be characterised by eight key stages (Thompson *et al.*, 1998):

1) Set objectives. These must be as precise as possible and clearly defined so as to enable the measurement of success or failure (Lindenmayer *et al.*, 2012). Lambert *et al.* (2009) break this stage down further into a) define the problem, b) identify and consult stakeholders, c) set a conservation goal, and d) define the objective so that it links with the goal. It is at this stage that inventory data may need to be collected if information cannot be gleaned from other sources e.g. expert opinions and publications.
2) Define the target area and/or population. This stage will inevitably be a trade-off between what is feasible given the resources/logistical constraints and the key requirements of the species/populations.
3) Choose the plot design and enumeration technique. Lambert *et al.* (2009) stress the importance of considering pre-existing monitoring designs and options, along with their limitations and biases, before attempting to design a new program or method. If the needs of the new program can be met with protocols that already exist, time and effort can be saved by sharing lessons learnt.
4) Consider the sources of variability. These can be numerous, and varying from environmental effects and habitat differences to observer effects.
5) Select an appropriate sampling regime.
6) Decide feasible sample sizes, taking into consideration resource availability.

7) Check that the proposed method has the power to meet the desired objectives.
8) Refine the method by repeating previous steps until the optimum trade-off is achieved between resource availability and power to meet desired objectives.

1.3 Challenges in monitoring cryptic species

Species that are described as ‘cryptic’ are those that are difficult to detect and are therefore inherently challenging to monitor. There are two challenges that can occur with monitoring these species, low detectability and high variability.

The first of these, the low probability in finding individuals, usually results in a high number of non-detections or zeros in the dataset. Such data are problematic because large sample sizes would be required in order to show the statistical significance of results (Clarke *et al.*, 2003; Tyre *et al.*, 2003). Unfortunately such large samples sizes are rarely feasible, particularly for rare and endangered species (Clarke *et al.*, 2003; MacKenzie *et al.*, 2005). Also, data that has a high proportion of zeros tends not to conform to a single standard distribution (e.g. normal, binomial or poisson) and is instead a mixture of a standard distribution (e.g. poisson) and a distribution with a point mass of one at zero (Royle & Nichols, 2003). Data that conforms to a mixture of distributions are complex to transform (Hall, 2000). This challenge often restricts the use of many analytical techniques and increases reliance on statistically strong sampling frameworks that are also impractical (Forcada, 2000; Hall, 2000). Resultant data have a limited ability to confirm threats and inform management decisions, as it is not possible to show a decline for a species that is present but not detected. This can mislead managers who are trying to prioritise limited conservation resources and efforts (Chadès *et al.*, 2008).

The second challenge, high variability, occurs because detection probabilities of cryptic species vary greatly spatially and temporally with environmental factors and habitat features. This impacts the precision and power of many monitoring methods (Seber, 1982 pp 19; Clarke *et al.*, 2003) but can be resolved if the detection probabilities of individuals can be accounted for (MacKenzie *et al.*, 2002; Royle & Nichols, 2003). When cryptic species are also rare and threatened these key challenges become even more complex.

A review of 30 publications, covering 28 different species, demonstrates that authors characterise species as 'cryptic' based on a broad range of factors (Table 1.1). These vary greatly from species to species, but largely fall into four categories: species that are visually cryptic, behaviourally cryptic, spatially cryptic and temporally cryptic (Table 1.1). Identifying the exact source of crypsis can help to focus the development of potential solutions, as species with similar cryptic characteristics share monitoring constraints; potentially making solutions applicable across these species. Based on this review, I describe these four cryptic characteristics as follows:

1.3.1 Visually cryptic

These are species that are difficult to see due their appearance and the way that this relates to their physical environment. For example, the species may have a small size, and live in thick vegetation, or those with camouflaged colourations (Table 1.1). The most common problem with visually cryptic species is low detectability and zero-inflated data (Table 1.2). An example of a visually cryptic species is the noisy scrub-bird (*Atrichornis clamosus*), a small, well-camouflaged, threatened passerine, endemic to south-western Australia (Portelli, 2004). This species inhabits thick vegetation in steep gullies (Smith & Robinson, 1975) making it difficult to see. As a result, traditional monitoring methods, such as mark-resight, detect too few individuals for results to be informative (Smith & Robinson, 1975; Portelli, 2004). However, male noisy scrub-birds produce a conspicuous territorial call throughout the year (Portelli, 2004). This call is used to map male territories, and has been used as a population index to measure trends across time and the effectiveness of management practices (Smith & Robinson, 1975; Smith & Forrester, 1981; Smith, 1985). However, calls from individual birds are not distinct enough to allow individuals to be identified (and therefore censused) through their calls (Portelli, 2004).

Table 1.1: Descriptions of cryptic characteristics reported by authors in 30 publications covering 28 different species, across four classes.

Mammalia	**Species Characteristics**									**Logistical Characteristics**						
	Visually cryptic			**Behaviourally cryptic**						**Spatially cryptic**			**Temporally cryptic**			
Species	Size	Looks[*]	Well hidden[†]	Low activity	Vocally quiet	Solitary/ sparse	Secretive/ evasive	Home range	Highly mobile[α]	Specialist skills[β]	High cost	Difficult access[δ]	Nocturnal/ crepuscular	Seasonally detectable	Tot.	Ref[‡],
Tiger *Panthera tigris*						✓	✓		✓		✓	✓	✓		6	1, 2, 3
Snow leopard *Uncia uncia*		✓				✓	✓	✓	✓			✓			6	4,5
Leopard *Panthera pardus*							✓	✓	✓				✓		4	6
Pygmy rabbit *Brachylagus idahoensis*							✓								1	7
Red fox *Vulpes vulpes*							✓						✓	✓	3	8
San Joaquin kit fox *Vulpes macrotis*		✓					✓						✓		3	9, 10
Blue duiker *Philantomba monticola*			✓				✓						✓		3	11
Suni *Neotragus moschatus*			✓				✓								2	11
Abbott's duiker *Cephalophus spadix*			✓				✓						✓		3	11
Tufted deer *Elaphodus cephalophus*							✓					✓			2	12
Golden monkey *Rhinopithecus roxellanae*							✓					✓			2	12
Wolf *Chrysocyon brachyurus*			✓			✓	✓	✓							4	13
Total constraints		2	4			3	12	3	3		1	4	6	1	39	

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[*] Looks or appearance e.g. well camouflaged in relation to the environment; [†] Well-hidden e.g. inhabits areas with thick vegetation or lives in burrows; [α] Highly mobile e.g. moves quickly between sampled sites; [δ] Access is difficult e.g. requires specialist equipment and/or or skills.

[‡] [1]Barlow, (2009); [2]Bhagavatula & Singh (2006); [3]Karanth *et al.,*(2011); [4]Jackson *et al.* (2006); [5]McCarthy *et al.* (2008); [6]Balme *et al.* (2009); [7]Sanchez *et al.,* (2009); [8]Vine *et al.,* (2009); [9]Smith *et al.* (2001) ; [10]Hole (2012); [11]Rovero & Marshall (2009); [12]Dajun *et al.* (2006); [13]Wasser *et al.* (2009).

Aves	**Species Characteristics**									**Logistical Characteristics**						
	Visually cryptic			**Behaviourally cryptic**						**Spatially cryptic**			**Temporally cryptic**			
Species	Size	Looks*	Well hidden§	Low activity	Vocally quiet	Solitary/ sparse	Secretive/ evasive	Home range	Highly mobileα	Specialist skillsβ	High cost	Difficult accessδ	Nocturnal/ crepuscular	Seasonally detectable	Tot.	Ref. **
Golden eagle *Aquila chrysaetos*							✓				✓				2	14
King rail *Rallus elegans*							✓								1	15
Western ground parrot *Pezoporus wallicus*		✓	✓				✓					✓	✓		5	16
Woodcock *Scolopax rusticola*		✓	✓				✓						✓	✓	5	17
Great gray owl *Strix nebulosa*		✓	✓				✓								3	18
Noisy scrub-bird *Atrichornis clamosus*	✓	✓	✓				✓	✓							5	19
Corncrake *Crex crex*	✓	✓	✓				✓						✓		5	20,21
Yellow rail *Coturnicops noveboracensis*	✓		✓	✓		✓									4	22
Sumatran ground cuckoo *Carpococcyx viridis*						✓	✓					✓			3	23
Sunda Thrush *Zoothera andromedae*						✓	✓					✓			3	23
Total constraints	**3**	**5**	**6**	**1**		**3**	**9**	**1**			**1**	**3**	**3**	**1**	**36**	

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* Looks or appearance e.g. well camouflaged in relation to the environment; § Well-hidden e.g. inhabits areas with thick vegetation or lives in burrows; α Highly mobile e.g. moves quickly between sampled sites; δ Access is difficult e.g. requires specialist equipment and/or or skills.

** [14]Pagel *et al.,* (2010); [15]Pierluissi & King (2008); [16]Burbidge *et al*. (2007); [17]Hoodless *et al.* (2008)*;* [18]Rognan *et al.* (2009); [19]Portelli (2004); [20]Peake & McGregor (2001); [21]Peake *et al.* (1998); [22]Robert & Laporte (1997); [23]Dinata *et al.* (2008).

Reptilia

	Species Characteristics									Logistical Characteristics						
	Visually cryptic			Behaviourally cryptic						Spatially cryptic			Temporally cryptic			
Species	Size	Looks*	Well hidden††	Low activity	Vocally quiet	Solitary/ sparse	Secretive/ evasive	Home range	Highly mobile$^{\alpha}$	Specialist skills$^{\beta}$	High cost	Difficult access$^{\delta}$	Nocturnal/ crepuscular	Seasonally detectable	Tot.	Ref‡‡
Sinbad skink *Oligosoma pikitanga*										✓		✓			2	24, 25
Mojave desert tortoise *Gopherus agassizii*			✓			✓	✓	✓							4	26
Flat-tailed tortoise *Pyxis planicauda*	✓	✓	✓												3	27
Brown treesnake *Boiga irregularis*		✓	✓												2	28
Total constraints	**1**	**2**	**3**			**1**	**1**	**1**		**1**		**1**			**11**	

Insecta

	Species Characteristics									Logistical Characteristics						
	Visually cryptic			Behaviourally cryptic						Spatially cryptic			Temporally cryptic			
Species	Size	Looks	Well hidden$^{\alpha}$	Low activity	Vocally quiet	Solitary/ sparse	Secretive/ evasive	Home range	Highly mobile	Specialist skills$^{\beta}$	High cost	Difficult access$^{\delta}$	Nocturnal/ crepuscular	Seasonally detectable	Tot.	Ref.
Bumble bee *Bombus* spp.	✓		✓			✓									3	29,30
Total constraints	**1**		**1**			**1**									**3**	

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* Looks or appearance e.g. well camouflaged in relation to the environment; †† Well-hidden e.g. inhabits areas with thick vegetation or lives in burrows; $^{\alpha}$ Highly mobile e.g. moves quickly between sampled sites; $^{\delta}$ Access is difficult e.g. requires specialist equipment and/or or skills.

‡‡[24]Browne *et al.,* (2006); [25]Edmonds & Whitehead (2010); [26]Cablk *et al.,* (2008); [27]Bal (2010); [28]Savidge *et al.,* (2011); [29]O'Connor *et al.,* (2012); [30]Waters *et al.,* (2010);.

Summary	**Species Characteristics**									**Logistical Characteristics**					
	Visually cryptic			**Behaviourally cryptic**						**Spatially cryptic**			**Temporally cryptic**		
Class	Size	Looks	Well hidden$^{\alpha}$	Low activity	Vocally quiet	Solitary/ sparse	Secretive/ evasive	Home range	Highly mobile	Specialist skills$^{\beta}$	High cost	Difficult access$^{\delta}$	Nocturnal/ crepuscular	Seasonally detectable	Tot.
Mammalia		2	4			3	12	3	3		1	4	6	1	39
Aves	3	5	6	1		3	9	1			1	3	3	1	36
Reptilia	1	2	3			1	1	1		1		1			11
Insecta	1		1			1									3
Total constraints	**5**	**9**	**14**	**1**		**8**	**22**	**5**	**3**	**1**	**2**	**8**	**9**	**2**	**89**

Visually cryptic juvenile cuttlefish, Credit: Wikimedia Commons.

1.3.2 Behaviourally cryptic

This category includes character traits of the species that are not related to their appearance and physical environment. For example, species that are inactive, solitary, sparsely distributed, secretive and/or evasive, where evasive means to purposely avoid contact with humans, sometimes at great lengths, and secretive means to be wary and shy (Table 1.1). In general, detection probabilities tend to be low for behaviourally cryptic species and the data tends to be zero-inflated (Table 1.2). Behaviourally cryptic species that have large or small home ranges can be relatively gregarious but are still behaviourally cryptic because, for these species, it is usually a challenge to sample the entire area of interest with the intensity required to achieve sufficient probabilities of detection (Thompson, 2004). This scenario creates detection probabilities that are variable because the probability of the species being detected at any one time depends upon its location with respect to the sampled area (Table 1.2). An example of a behaviourally cryptic species is the endangered Bengal tiger (*Panthera tigris*). This species inhabits remote parts of India (Bhagavatula & Singh, 2006) and is behaviourally cryptic because individual tigers are solitary and evasive/secretive, preferring to avoid human contact where possible (Barlow *et al.*, 2009). Monitoring options currently being explored for this species include: a) sign surveys to determine occupancy (Karanth *et al.*, 2011), faecal DNA sampling as an index representing sex-ratio or a non-invasive alternative to capture-mark-recapture (Bhagavatula & Singh, 2006), and b) camera trapping (photographically ‘capturing’ animals) as an index of abundance (Carbone *et al.*, 2001) or an index of resident/breeding individuals (Barlow *et al.*, 2009).

1.3.3 Spatially cryptic

Spatially cryptic characteristics are less concerned with the species itself and relate more to the logistical constraints that occur as a result of the species’ location (i.e. they are challenges relating to people and their inability to access the same spatial area as the species). For example, species that inhabit inaccessible locations, such as cliffs or deep sea, may be gregarious and bold in colouration, but still remain difficult to detect. Relevant logistic constraints include the need for specialist equipment or staff with task-specific skills and high levels of fitness (Table 1.1). Such constraints commonly result in small sample sizes and/or biased sampling intensities (Table 1.2). For example, to date, the Sinbad skink (*Oligosoma pikitanga*) has only been found on a single cliff-face, in the Sinbad Gully of Fiordland, New Zealand (Willans & Wickes, 2010). Access to the area requires a helicopter and the site can only be accessed by rock climbing, which requires specialist skills and equipment (Plate 1.1, Plate 1.2) (Edmonds & Whitehead, 2010). Attempts to find new populations have so far been unsuccessful and have been hindered by short weather windows and access constraints, preventing sufficient coverage of all areas of potentially suitable habitat (Edmonds & Whitehead, 2010).

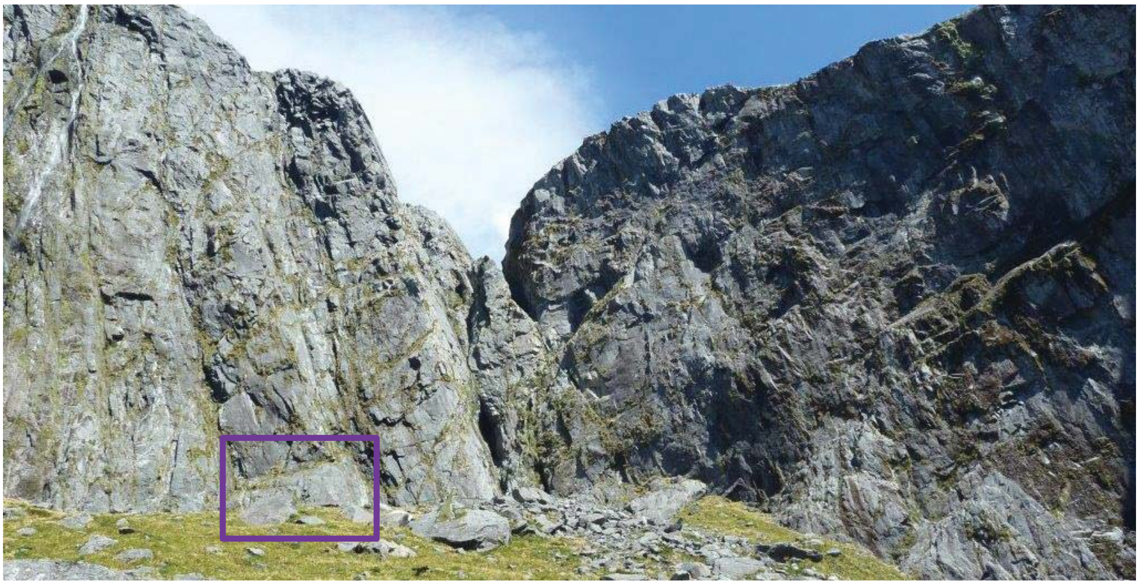

Plate 1.1: Upper Sinbad Gully in Fiordland, where the only known population of Sinbad skinks is located. The skink population is located in the rock crevices and vegetation to the right of the waterfall (shown by the square; Plate 1.2 shows an enlarged image of this area). Access to the area requires a helicopter. Once in the area, access to the skink population requires rock climbing skills and equipment. Credit: C O'Donnell

Plate 1.2: An enlargement of the rock crevice where the only population of Sinbad skinks has been found to date. Image shows two rock climbers surveying for skinks (circled). The logistical constraints experienced in accessing the site can be overcome but are costly in terms of time and money. Credit: C O'Donnell

1.3.4 Temporally cryptic

These characteristics relate more to the logistical constraints caused when accessibility or detectability of a species is constrained to a limited timeframe (Table 1.1). Inferences of such data often become limited or biased by factors associated with site accessibility. Also, when variability cannot be explained, as is often the case with these constraints, the probability of detection becomes heterogeneous and results less meaningful (Table 1.2). For example, some birds only call at certain times of the day, month and/or year. One such bird includes the woodcock (*Scolopax rusticola*), a secretive, well camouflaged forest bird that is both visually and behaviourally cryptic. Male woodcocks perform conspicuous crepuscular display flights (called ‘roding’) that can be used as an index of breeding abundance (Hoodless *et al.*, 2008). Despite this, the window for detecting individuals using roding as a cue is short and limited to the breeding season. Thus, although the use of this method allows managers to overcome some of the challenges posed by the species’ behavioural and visual characteristics, monitoring for the species remains temporally limited.

Table 1.2: Summary of monitoring constraints associated with cryptic species based on a review of 30 publications, covering 28 different species.

			Restriction (✓= restriction caused by cryptic characteristic)			
			Small sample size	Low detections	Variable detection probabilities	Inferences limited by sampling regime
Species characteristics	**Visually cryptic**	Small size		✓		
		Looks[*]		✓		
		Well hidden[‡‡]		✓		
	Behaviourally cryptic	Low activity		✓		
		Vocally cryptic e.g. short, quiet calls		✓		
		Solitary or sparsely distributed		✓	✓	
		Secretive or evasive		✓		
		Small or large home ranges		✓	✓	
		Highly mobile[α]		✓	✓	
Logistical characteristics	**Spatially cryptic**	Specialist equipment or skills[β]	✓			✓
		High cost	✓			✓
		Access is taxing or time consuming[δ]	✓			✓
	Temporally cryptic	Nocturnal or crepuscular			✓	✓
		Seasonally detectable			✓	✓

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[*] Looks or appearance e.g. well camouflaged in relation to the environment; [‡‡] Well-hidden e.g. inhabits areas with thick vegetation or lives in burrows; [α] Highly mobile e.g. moves quickly between sampled sites; [δ] Access is difficult e.g. requires specialist equipment and/or or skills.

1.3.5 Challenges of multiple cryptic characteristics

Often a species will be difficult to detect due to a range of cryptic characteristics. For example, the western ground parrot (*Pezoporus wallicus*), is a solitary, secretive, evasive parrot that forages mostly on the ground in thick vegetation (McFarland, 1991; Burbidge *et al.*, 2007) making it both visually and behaviourally cryptic. Current monitoring relies on detection of its calls, which are largely produced before sunrise and after sunset (McFarland, 1991) making it also temporally cryptic. Additionally, the species is found in remote areas of Western Australia far from human settlements (Burbidge *et al.*, 2007) making it also spatially cryptic. Some species are cryptic in certain environments but not in others. For example, red foxes (*Vulpes vulpes*) are largely conspicuous in urban habitats (Adkins & Stott, 2006), but can be difficult to detect elsewhere because of their nocturnal habits and post-persecution evasiveness (Sadlier *et al.*, 2003; Vine *et al.*, 2009).

Sometimes solutions to one cryptic challenge creates another challenge. For example, in the case of the endangered Bengal tiger, this species was defined above as behaviourally cryptic because of it’s secretive, evasive and solitary behaviours. Managers solved this problem by designing a method that detects the animal when it is not physically present e.g. counting tracks and signs (Barlow *et al.*, 2009). However, detection rates using this method were particularly low (< 21%, Barlow *et al.*, 2009; Karanth *et al.*, 2011). This eventually led to the development of a camera trapping method that produced more favourable detection rates (79%, Barlow *et al.*, 2009). This difference in detectability between methods is not directly discussed in Barlow *et al.* (2009), however they do discuss how their sign-based method is restricted to accessible tracks and roads, which could account for a lower detectability rate (suggesting some spatial crypsis was being introduced by this method). This challenge did not occur with the camera trapping method because these devices were deployed systematically to allow coverage of the entire 100 km^2 study area, thus solving any spatially cryptic conundrums.

Due to the challenges of monitoring cryptic species, species that may be threatened are often classed as data deficient because it is too difficult to gather information about them (Townsend *et al.*, 2008). These species often end up in conservation management's 'too hard basket'. This may explain why monitoring efforts in New Zealand have tended to be biased towards those species that are easier to monitor (Lee *et al.*, 2005). This is understandable, as it is difficult and costly to develop an effective monitoring method while behavioural and biological knowledge is lacking (Chapter 6). However, monitoring is critical for many cryptic species, as they are often endangered and/or have specialised habitat requirements. Lack of monitoring methods for these species can impede the ability to identify and understand threats and population trends, confound management decisions, and limit a project's ability to compete for funding (Clarke *et al.*, 2003; Chadès *et al.*, 2008). A species in decline that remains data deficient will only become more difficult to detect as it gets rarer, inevitably resulting in extinction. Hence, it is crucial to ensure that preferential treatment is not given to species that are easier to monitor (Clarke *et al.*, 2003).

1.4 Options for monitoring cryptic species

Overcoming many of the challenges associated with cryptic species can be costly in terms of time, money and patience (Thompson, 2004). However, the chances of successfully monitoring a cryptic species can be improved by focusing on achieving: a) a sampling procedure that spreads the sampling effort over a large area; and b) monitoring options that attain minimum probabilities of detection within each sampling unit (Thompson, 2004).

Monitoring options for wildlife can be broadly categorised as either complete counts (census) or incomplete counts (Thompson *et al.*, 1998). Complete counts involve the enumeration of 'the total number of animals inhabiting a study area' (Caughley, 1977). Although they are ideal, complete counts are rarely feasible even with the most gregarious species (Thompson *et al.*, 1998) and tend to be resource-thirsty. Instead, monitoring of cryptic species will inevitably rely on incomplete counts, as these do not require that all individuals within a sampling unit are counted. These counts are represented by the relationship between the number of individuals observed, the probability of detection and the true number of individuals in the population (Thompson *et al.*, 1998). There are two types of incomplete counts, those that measure and account for detectability (e.g. mark-recapture, distance sampling) and those where detectability is immeasurable or assumed to be constant (indices).

Indices are defined as ‘any measurable correlative of density’ (Caughley, 1977). Index methods include direct measures of the target species such as the number of stoats trapped per night (Keedwell & Brown, 2001), or indirect measures such as the number of latrines per unit area (Wronski & Plath, 2010) or the number of prey items per transect (Watson *et al.*, 1992). In general, the stronger and more direct the relationship between the measure and the density of the species/population of interest, the more informative the index becomes. However, for the purpose of showing long-term trends, any index will be informative provided that the following assumptions are met: a) the probability of detection is independent of the true abundance (Johnson, 2008); b) the probability of detection is independent of any covariate that true abundance depends on (Etterson *et al.*, 2009); and c) the variation in the population size is greater than any variation in detection (Johnson, 2008).

1.5 Developing monitoring methods for cryptic species: the Australasian bittern as a case study

The Australasian bittern (*Botaurus poiciloptilus;* matuku) is a cryptic, endangered swamp bird occurring in New Zealand, New Caledonia and southern Australia (BirdLife International, 2014). Conservation managers are interested in identifying factors that cause the decline of bitterns so that key habitats can be managed to reverse these declines (Buchanan, 2009; O'Donnell, 2011). To date, no monitoring methods have been developed for application in New Zealand but a range of methods have been trialled on closely related bittern species in Europe and America (Gibbs & Melvin, 1997; Puglisi *et al.*, 1997; Polak, 2006). These methods are based on call-counts and rely on the ability to detect the deep resonant breeding call (boom) of male bitterns. Depending upon the exact technique used, these methods represent indices of abundance or conspicuousness for breeding populations, and have shown great potential as tools for inventory and monitoring (Poulin & Lefebvre, 2003; Polak, 2006). Australasian bitterns are known to produce similar calls (here after referred to as ‘booms’) (Teal, 1989). It is possible that methods that have proven successful overseas may be applicable here in New Zealand (Gilbert, 2006).

Australasian bitterns are large, stocky birds (≈ 71 cm in height, Heather & Robertson, 1996). Despite this, they are difficult to see at any time of year (Teal, 1989). They are among the most camouflaged bird species in New Zealand (Plate 1.3), being both visually and behaviourally cryptic. Their plumage is streaky dark-brown and beige, perfectly matching their habitat (Heather & Robertson, 1996). In general, their movements are slow and cautious (Heather & Robertson, 1996). When approached they have been known to either move away quietly, adopt the 'freeze' posture[*], drop down and flatten their torsos to the ground[†], or take flight slowly and laboriously. The latter behaviour, taking flight, is the only action that is conspicuous. However, Teal (1989) also noted, that when approached, bitterns rarely take flight unless within 20 m of the observer, making it entirely plausible that a bittern could remain undetected even when in close proximity to a person.

Australasian bitterns are also spatially cryptic. They are wetland specialists, occupying habitats that are difficult to traverse and are rarely visited. Studies in Whangamarino wetland, New Zealand, suggest Australasian bitterns mostly inhabit mineralised and semi-mineralised wetlands (Ogle & Cheyne, 1981), although they are sometimes observed foraging in drains and wetland/farmland edges (pers. obs.).

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[*] The 'freeze' or "surveillance' posture is a common behaviour for bitterns and involves them standing still with neck fully erect, and bill pointing skywards. This posture causes the striations of their plumage to align and blend in with the surrounding vegetation making them very difficult to see (Teal, 1989; Whiteside, 1989; Heather & Robertson, 1996).

[†] Dropping their torso's to the ground also causes them to disappear completely and suddenly from view (Heather & Robertson, 1996).

Plate 1.3: The Australasian bittern (shown by the arrow) is one of the most cryptic bird species in New Zealand. Credit: Peter Langlands.

As a result of the challenges faced in detecting this species, Australasian bitterns are under-researched here in New Zealand (Ogle & Cheyne, 1981; Teal, 1989; Whiteside, 1989; O'Donnell, 2011). Yet knowledge regarding bittern populations has never been more important. National bittern numbers appear to be low. As early as the 1980s, New Zealand’s bittern population was thought to be <800 birds, and threatened by habitat loss (Heather & Robertson, 1996). These threats have only increased with time. Bitterns are reliant on wetlands to breed and feed, and as current wetland areas represent only 10% of their original extent (Cromarty & Scott, 1996; Ausseil *et al.*, 2011), it is expected that the decline in bittern populations in New Zealand is severe. Even today, very little literature exists regarding actual threats, and what information is available is often inferred from closely related species (e.g. Teal, 1989; O'Donnell, 2011).

1.6 Thesis aims and objectives

In New Zealand, there is a need for a monitoring method that allows a greater understanding of Australasian bittern populations. There is a specific need for a method that can show: a) status, distribution and threats; b) identification and protection of key sites; and c) the response of populations to management (Kushlan, 2007; O'Donnell, 2011). To achieve this, monitoring options are required that are informative both on a local level (to determine threats and response to management), and on a national level (to identify important sites, determine distribution and confirm threats).

Despite recent advances in developing monitoring methods for other cryptic species, there is little information available that managers can use to help determine which monitoring options are feasible for Australasian bitterns. To address this, there is a need to review methods that are available from similar cryptic species to see if they can be used for Australasian bitterns. In particular, managers require options that can be used to identify, reduce and measure potential sources of error that result from the cryptic characteristics of bitterns.

A sampling regime is required that is informative with regard to the above objectives. This is particularly challenging in the case of monitoring bitterns because many areas of their habitat are inaccessible and the species is thought to be crepuscular. All of these factors constrain the development of a sampling regime that will be unbiased and informative. Managers require options that allow the measurement of these biases, or that can be used to overcome or reduce these constraints.

Therefore, in keeping with the stages of developing a monitoring method, outlined by Thompson *et al.,* (1998), the specific objectives of this thesis are to:

1) Review potential monitoring options for Australasian bitterns and their feasibility (Chapter 2)

Then, based on the method determined to be the most feasible in Chapter 2, I intend to:

2) Identify and quantify any associated sources of variability (Chapter 3)
3) Identify tools that are currently available and have shown potential with species that have similar cryptic characteristics to bitterns, and test these tools on Australasian bitterns to determine whether they reduce the sampling restrictions associated with the cryptic nature of bitterns (Chapter 4)
4) Examine whether modelling can be used to predict abundance from calling-rate (Chapter 5)
5) Examine whether the method assumptions are reasonable in terms of the natural behaviours of the species (Chapter 6)

This knowledge will assist managers in developing reliable monitoring methods for Australasian bitterns that will their fulfil objectives on a project-by-project basis, as well as provide a monitoring framework that can be applied nationally. The ability to monitor Australasian bitterns effectively on a local and national level will further our understanding of this data deficient and nationally endangered species, allowing greater prioritisation of research and accountability of future management practices.

Furthermore, the challenges associated with developing a monitoring method for Australasian bitterns are not unique and are shared by many cryptic species (Table 1.1). As a result, the process of developing a monitoring method for Australasian bitterns that is outlined in this thesis, will be applicable other cryptic species and may help to identify and address some of the challenges currently limiting our ability to monitor these species.

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2

Options for monitoring cryptic Australasian bitterns in New Zealand: a review

The Australasian bittern, a cryptic secretive wetland bird. Credit: Adrienne Grant

2.1 Introduction

Development of an effective monitoring method for a species may take considerable time, money and effort. Development of a monitoring method for a cryptic species can be even more complex, as there is a need to overcome some of the limitations caused by the cryptic characteristics of these species (Chapter 1). However, many of these characteristics are shared across species, so the challenges of monitoring them are also often similar (Chapter 1). As a result, solutions found for the monitoring problems of one cryptic species may be applicable to others; and time, money and effort may be saved by adapting existing protocols.

There is a need to develop a monitoring method for Australasian bitterns in New Zealand (Buchanan, 2009; O'Donnell, 2011). In this chapter, I identify the cryptic characteristics of other bittern species (Botaurinae), outline which monitoring options have been tried for these species and assess their potential applicability for Australasian bitterns. I also examine some potential cues that have yet to be tried on bitterns, but have been used to detect other species that are similarly cryptic. Finally, I summarise these findings to establish which knowledge gaps are worth pursuing to allow further development of method(s) that can be used for Australasian bitterns.

2.2 Cryptic characteristics of bittern species

The Australasian bittern (*Botaurus poiciloptilius*) is one of 12 living bittern species that make up the subfamily *Botaurinae*, within the heron family *Ardeidae* (Kushlan & Hancock, 2005). *Botaurinae* can be divided into two genera, the morphologically larger *Botaurus* and the smaller but more diverse *Ixobrychus* (Hancock & Elliot, 1978; Hancock & Kushlan, 1984). In general, all bittern species are cryptic, although the cinnamon bittern (*I.cinnamomeus*), Schrenck’s bittern (*I. eurhythmus*) and yellow bittern (*I.sinensis*), are slightly more visible because they inhabit less dense vegetation (Table 2.1). The dwarf bittern (*I. sturmii*) is the least cryptic, being described as ‘not noticeably shy or hard to see’ (Hancock & Kushlan, 1984), but it is still rare with nocturnal tendencies (Kushlan & Hancock, 2005). Despite these small differences in conspicuousness, all 12 bittern species are poorly understood, with little or no information available regarding their abundance and distribution (Hancock & Elliot, 1978; Hancock & Kushlan, 1984; Kushlan & Hancock, 2005). The three most studied of these species are the Eurasian bittern (*B. stellaris*), American bittern (*B. lentiginosus*) and least bittern (*I.exilis*) (Table 2.2), all of which share similar cryptic characteristics with the Australasian bittern (Table 2.1). As a result, monitoring options that work for these species may also prove useful for Australasian bitterns.

Table 2.1. Cryptic characteristics of the 12 species of the bittern subfamily, Botaurine, based on information from Hancock & Kushlan (1984) and Kushlan & Hancock (2005); a ✓symbolises a characteristic that has been noted as applicable to that species.

	Species Characteristics				**Logistical Characteristics**
	Visually cryptic		**Behaviourally cryptic**		**Temporally cryptic**
	Camouflaged colouration	Well hidden	Slow and stealthy	Secretive or evasive	Nocturnal or crepuscular
Botaurus					
Eurasian 'Great' bittern *B. stellaris*	✓	✓	✓	✓	✓
Australasian bittern *B. poiciloptilius*	✓	✓	✓	✓	✓
American bittern *B. lentiginosus*	✓	✓	✓	✓	Not stated
South American bittern *B. pinnatus*	✓	✓	✓	✓	Not stated
Ixobrychus					
Black bittern *I. flavicollis*	✓	✓	✓	✓	✓
Least bittern *I. exilis*	✓	✓	✓	✓	Not stated
Stripe-backed bittern *I. involucris*	✓	✓	More active - runs up and down darting into vegetation	✓	✓
Little bittern *I. minutus*	✓	✓	✓	People tolerant	Diurnal
Schrenck's bittern *I. eurhythmus*	✓	Easier to see - frequents grasslands	✓	✓	Crepuscular feeder, (not exclusively)
Cinnamon bittern *I. cinnamomeus*	✓	Easier to see - frequents grasslands and man-made habitats	✓	Less shy	✓
Yellow bittern *I. sinensis*	✓	Less dependent on dense vegetation	More active - runs down prey	Less shy	✓
Dwarf bittern *I. sturmii*	"Not noticably shy or hard to see"				✓

Plate 2.1: An Australasian bittern in freeze pose. When disturbed bitterns often adopt this pose, which makes them difficult to detect visually because striations on their plumage line-up perfectly with the vegetation in their habitat (here, raupō, Typha sp.). Photo was captured on a trail camera at Lake Whatumā, Central Hawkes Bay, Spring 2014. Credit: Lake Whatumā care group.

2.3 Current monitoring practices for bittern species

Ideally, managers would use complete counts, such as true or plot counts, to monitor bitterns (Thompson *et al.*, 1998). However, these types of counts are not feasible for most species, let alone cryptic bird species like bitterns (Chapter 1). Indeed, current monitoring practices for bittern species are largely restricted to incomplete counts corrected for detectability, incomplete counts not corrected for detectability (indices), best guesses, or site occupancy (Table 2.2).

2.3.1 Incomplete counts corrected for detection

Incomplete counts involve counting the number of individuals in a sampling unit, rather than attempting to count an entire population. For incomplete counts to be informative with regard to the entire population, it is necessary to quantify the probability of detection so that the true number of individuals in the sampling unit can be estimated (Thompson *et al.*, 1998).

For an animal to be detected two conditions must be met: 1) the animal must be available for detection (availability), and 2) the observer must be able to perceive that animal assuming that it is available (perceptibility) (Farnsworth *et al.*, 2002; Thompson, 2004; Diefenbach *et al.*, 2007; Johnson, 2008). It is important to be aware of this distinction with incomplete counts corrected for detectability because factors that affect detectability are really a product of factors that affect availability and perceptibility. Factors that influence availability are those out of the observer's control, such as whether the animal is actually present in the sample area, and in the correct state to be detected given the sampling method used (Thompson, 2004). A bird that is present may be available for detection using a method that involves visual detection, but unless it calls it is not 'available' to be detected during a call-count survey. Factors that affect perceptibility are easier to control or measure and include: observer experience, weather variables, signal attenuation and habitat (Alldredge *et al.*, 2007).

Development of incomplete monitoring methods that are corrected for detectability is desirable, as the ability of these methods to measure or correct for variable detection probabilities means they can provide unbiased population estimates with a measurable level of precision. Such a method can also be used simultaneously with cheaper indices (Section 2.3.2 below) to double sample a population, allowing the identification of potential sources of variability and providing an assessment of the effectiveness of indices (Thompson *et al.*, 1998; Bogner & Baldassarre, 2002b; Polak, 2006). There are three incomplete count methods that have shown potential as monitoring options for other bittern species: territory-mapping, nest searching and mark-recapture (Table 2.2).

Table 2.2. Current monitoring of Botaurine species. Symbols represent a subjective assessment of the effectiveness of a method in relation to publication objectives: an effective method (✓) was one informative in terms of the objectives; an ineffective method (✗) was uninformative in terms of objectives; and an ambiguous method (?) presented information that conflicted with other studies or was incomplete. Blanks cells indicate no information could be found. No publications were found to suggest double observer, distance sampling or time of arrival approaches had been used for bittern species. Numbers link to the references of each assessment symbol, which can be found in the last column.

Botaurus	Method used (✓ = Effective; ✗ = Ineffective; ? = Effectiveness not known)						
	Territory-mapping (Calls/sightings)	Territory-mapping (Nests)	Mark-Recapture	Occupancy	Index counts	Best guess	References
Eurasian bittern	✓[1,2,3,4,5,6,7,8]	✓[9,10,1,2]	✓[11] ?[12]	✓[2]	✓[3] ?[13]	?[14,15,16,17,18]	[1] Adamo *et al.* (2004); [2] Gilbert *et. al.,* (2007); [3] Lefebvre & Poulin (2003); [4] Poulin *et al*., (2005); [5] Poulin & Lefebvre (2003); [6]Poulin *et al*., (2007); [7] Van Turnhout *et al*., (2010); [8]Van Turnhout *et al.*,(2006); [9] Puglisi & Bretagnolle (2005); [10] Gilbert *et. al.,* (2003); [11] Gilbert *et al*., (1994);[12] Puglisi & Adamo (2004); [13] Ma *et al*., (2009); [14] Pellantova *et al*., (1993); [15] Bankovics (1991); [16] Kotagama (2006); [17] Warakagoda&Sirivardana (2006);[18] Kolecek & Reif (2011)
Australasian bittern	✓[19] ?[20,21,22]				✓[19] ?[23,21,22,]		[19] Pierce (2004); [20] Teal (1989); [21] Holzapfel (2006); [22] IMU (2005); [23] Casanelia *et al.* (2009)
American bittern				✓[24]	✓[24,25,26,27,28,29,30] ?[31,32,33]		[24] Conway & Nadeau (2010); [25] Gibbs & Melvin (1997); [26] Allen *et al.,* (2004); [27] Gibbs & Melvin (1993); [28] Lor & Malecki (2002); [29] Fletcher *et al.,* (2000); [30] Nadeau *et al.,* (2008); [31] Ribic *et al.,* (1999); [32] Fleury & Sherry (1995); [33] Ralph *et al.*,(2012)
South American bittern					?[34]	?[35,36]	[34] McKay (1980); [35] Eisermann & Avendaño (2006); [36] Gochfeld (1973);

Ixobrychus	Method used (✓ = Effective; ✗ = Ineffective; ? = Effectiveness not known)						
	Territory-mapping (calls/sightings)	Territory-mapping (Nests)	Mark-Recapture	Occupancy	Index counts	Best guess	References
Least bittern		✓[37,38]	✓[37]	✓[39]	✓[39,40,41,42,43,38] ?[44,45,46,]	?[47]	[37] Bogner & Baldassarre (2002b); [38] Bogner & Baldassarre (2002a); [39] Conway & Nadeau (2010); [40] Gibbs & Melvin (1993); [41] Lor & Malecki (2002); [42] Nadeau *et al.,* (2008); [43] Budd & Krementz (2010); [44] Allen *et al.,* (2004); [45] Ribic *et al.* (1999); [46] Fleury & Sherry (1995); [47] Gochfeld (1973);
Yellow bittern		✓[48]			✓[49] ?[50,51,56]	?[53,54,55]	[48] Lansdown & Rajanathan (1993); [49] Rajpar & Zakaria, (2010); [50] Zakaria & Rajpar (2010); [51] Ma *et al.,* (2009); [53] Gopi & Pandav (2007); [54] Kotagama (2006); [55] Warakagoda & Sirivardana (2006); [56] Gerlach & Skerrett (2002)
Stripe-backed bittern					?[56,57]	?[58,59,57]	[56] McKay (1980); [57] Romano *et al.,* (2005); [58] Gochfeld (1973); [59] Sick (1962)
Schrenck's bittern					✓[60] ?[61,62]		[60] Rajpar & Zakaria, (2010); [61] Zakaria & Rajpar (2010); [62] Ma *et al.,* (2009);
Black bittern						?[63,64,65,66,67]	[63] Gopi & Pandav (2007); [64] Kratter *et al.,* (2001); [65] Kotagama (2006); [66] Warakagoda & Sirivardana (2006); [67] Kratter *et al.,* (2001)
Little bittern	✓[68,69]	✓[68]			✓[70] ?[71]	?[72,73,74,75]	[68] van Turnhout *et al*., (2010); [70] Benassi *et al*., (2009); [71] Casanelia *et al.* (2009); [72] Sanderson *et al.,* (2006); [73] Pellantova *et al*., (1993); [74] Bankovics (1991); [75] Kolecek & Reif (2011)
Cinnamon bittern		✓[76]			✓[76,77] ?[78]	?[79]	[76] Lansdown & Rajanathan (1993); [78] Zakaria & Rajpar (2010); [77] Rajpar & Zakaria, (2010);[79] Gopi & Pandav (2007)
Dwarf bittern							

2.3.1.1 Territory-mapping – using calls and sightings

Territory-mapping involves plotting the spatial locations of all individuals of the target species that are found within a defined area (Davis & Winstead, 1980; Sutherland *et al.*, 2004). By repeating surveys throughout the sampling period, discrete territories can be defined using the clustered locations of individual observations (Thompson *et al.,* 1998). As a method, territory-mapping is useful for any species that have well-defined home ranges (Bibby *et al*., 1992). Territory-mapping can be used to estimate breeding density/abundance as well as an index method (Thompson *et al*., 1998). Seven assumptions must be met for this method to be useful (Bibby *et al*., 1992; Sutherland *et al*., 2004):

1) Observers are competent at locating and identifying birds.

2) Individual birds must be well spaced with no overlap between territories.

3) Individual birds must have high site fidelity throughout the sampling period.

4) The probability of detecting at least one individual from each territory must be high enough for each visit to allow all territories to be defined as clusters across the entire sampling period.

5) Birds are located and mapped accurately.

6) Individual birds must not be double counted during each visit.

7) Sampling is standardised as much as possible to limit bias from factors such as weather conditions, time of day and number of visits**.**

For Australasian bitterns, there is potential for all seven of these assumptions to be met for low-density populations in small wetlands during the breeding season (September-November). Bitterns are still rarely visible during this time (Plate 2.1) but instead males produce distinctive, easily recognisable calls referred to as ‘booms’. Territorial behaviours and site fidelity have not been studied for this species but calls appear to come consistently from discrete territories (Teal, 1989) suggesting assumptions one, two and three could be easily met for Australasian bitterns.

The fourth assumption, the probability of detecting an individual from a territory (PDT), is necessary for ensuring that birds have not been missed. PDT is a function of the conspicuousness of the species, and therefore is an inherent challenge for most visually and behaviourally cryptic species (Chapter 1). To detect sufficient individuals when PDT is low, requires a greater number and longer duration of visits (Svensson, 1979). PDT can be improved by identifying times and conditions that optimise detection probabilities (Svensson, 1979). For counts based on Australasian bittern calls, PDT will vary with factors that affect their calling-rate (see Chapter 3). However, as calling is thought to have a territorial function (Teal, 1989), it should be possible to predict the optimum time when the majority of birds are calling.

The fifth assumption, that birds are located and mapped accurately, will depend upon site accessibility for bitterns. If the site is accessible male calling bitterns could be mapped by approaching calling males quietly in a kayak or on foot and circumnavigating calling birds until their locations can be confirmed (close approaches). For sites that are inaccessible, bitterns could be monitored using ‘acoustic triangulation’, a method that allows Eurasian bittern territories to be mapped without disturbing birds or the need to access all areas (Lefebvre & Poulin, 2003). Acoustic triangulation is possible because the booms of Eurasian bitterns are far-reaching (Lefebvre & Poulin, 2003); a trait that is shared with Australasian bitterns (Teal, 1989). The method involves an observer, or multiple synchronised observers, taking several compass bearings to determine the direction of the origin of each bird’s call from fixed locations (Lefebvre & Poulin, 2003). These are plotted so that a location for each bird can be approximated where bearings intersect (Lefebvre & Poulin, 2003). Approximate locations can then be used to determine the distribution of bitterns, food preferences and habitat requirements (Lefebvre & Poulin, 2003; Adamo *et al*., 2004; Gilbert *et al*., 2005; Poulin *et al*., 2005; Poulin *et al*., 2007). Precise mapping of bitterns is limited by the accuracy and precision of bearings, the number of bearings taken and the difference in angles between bearings. To plot territories precisely, large numbers of bearings are required, which can make the method inefficient in terms of time and effort (Lefebvre & Poulin, 2003).

Factors such as wind speed, the occurrence of poor booms[*], and the distance of the bird from the observer, are known to affect bearing precision with Eurasian bitterns (Lefebvre & Poulin, 2003). Often birds with territories that are close together can only be distinguished and mapped if the calls of both birds overlap occasionally; something that will be limited by those factors that affect PDT (or the calling-rate).

Another limitation of territory-mapping is that the spatial locations of individuals would appear less clustered as bird densities increase (Bibby *et al.*, 1992). This would confound abilities to define territories (invalidating assumption 2) and affects the accuracy and precision of estimates. Furthermore, when calling-rate and/or the number of individuals is high, observers often have insufficient time to accurately record, locate and keep track of each calling bird. Under these circumstances it becomes impossible to get fixes that are precise and accurate enough to locate all birds, forcing observers to either focus on detecting every individual at the expense of measuring each bird's location accurately and precisely (meeting assumption 4 but invalidating assumption 5) or obtaining accurate and precise locations for some birds at the expense of detecting others (meeting assumption 5 but invalidating assumption 4). Longer sampling periods may reduce this trade-off, but will in turn increase the chance that birds move during sampling periods, possibly introducing errors through double counting (invalidating assumption 6). Also, the survey intensity required to map territories limits its feasibility for large wetlands (Sutherland *et al.*, 2004) because it is impossible to sample the entire area in one visit without vast numbers of observers. This can increase the variability of data through changes in factors such as environmental conditions (assumption 7) and the movement of individuals between periods (assumption 6). Thus the larger the wetland and the higher the density of birds, the harder it is to meet assumptions and ensure accurate and precise estimates.

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[*] 'Poor booms' are cough-like, inconsistent, unstructured calls. For a more comprehensive definition refer to Gilbert *et al*. (1994).

Recommendations for assumption seven, the need to conduct surveys under standardised conditions, are provided by the International Bird Census Committee (1969), Svensson (1979) and Bibby *et al*. (1992). Lefebvre & Poulin (2003) also outlines helpful suggestions that are more specific to acoustic triangulation. However, to apply these recommendations to Australasian bitterns, there is a need to understand more about the factors that affect the calling-rate of this species and therefore an observer's ability to predict the optimum time and conditions for achieving a high PDT (Chapter 3).

2.3.1.2 Territory-mapping using nests

Nest searching can be used to estimate productivity or abundance of breeding pairs (Thompson *et al*., 1998). The ability to directly measure the breeding population is advantageous as it potentially increases the power to detect population growth and identify threats associated with that population (White *et al*., 2006). For many species, nest searching can be more effective as a monitoring method compared to mapping territories by calls or sightings because the presence of a nest usually indicates the presence of both a male and a female, even if one or more of these birds are never seen (Bibby *et al*., 1992). Also, once found, nests are easily monitored, therefore allowing quick confirmation of the survival of the pair across the entire study period.

Mapping the territory calls of male bitterns is obviously problematic because it provides no information about female bitterns. In fact, the Eurasian bittern is polygynous, meaning the presence of a booming male can indicate the presence of between zero and five nesting females (White *et al*., 2006). This confounds a manager's ability to measure recruitment rates and true population growth. It also relies on the assumption that threats and mortality rates are the same for all ages and sexes; something that could feasibly be incorrect. Therefore, mapping territories using the locations of nests instead of male territories (or mapping a combination of both) would be preferable. Unfortunately, previous attempts to locate nests for Australasian bitterns suggest they are difficult to find (Teal, 1989), meaning the PDT (assumption 4) may be too low for this method to be useful for mapping pairs.

Plate 2.2: Australasian bittern chicks in a nest found in raupō at Lake Whatumā, October 2011. This nest contained two chicks and one infertile egg, but only one chick is fully visible in this photo. This nest was found by listening for the unique call produced by the chicks. Credit: E.Williams.

Methods for locating nests have been published for four of the 12 bittern species: the Eurasian, yellow, cinnamon and least bitterns (Table 2.2). For these species, nests were detected using one of three approaches. The first, used for all four bittern species, involves observers flushing nesting females, or visually looking for signs of a nest while walking transects that are spaced a few metres apart (Lansdown & Rajanathan, 1993; Bogner & Baldassarre, 2002a; Puglisi & Bretagnolle, 2005). This is intrusive and should be used with caution for Australasian bitterns, as even small disturbances could negatively impact nest success (Teal, 1989; O'Donnell, 2011). It also may not be practical for wetlands that have sensitive flora or are inaccessible.

The second approach involves observing an area for female foraging flights. This approach is commonly used to find the nests of Eurasian bitterns in the United Kingdom, where females conspicuously fly to and from their nests to feed (Mallord *et al*., 2000; Adamo *et al*., 2004; White *et al*., 2006). This approach is less intrusive; but it is also very time consuming as observers may need to watch the wetland for at least 5 hours to detect flying females (Gilbert, 2006). In addition, there may be many false alarms, as males and non-breeders also could undertake foraging flights from their territories. It is currently not known if Australasian bitterns have similar conspicuous nesting behaviours that could be exploited in this way, and whether these behaviours would be predictable enough to be relied upon. Despite the popularity of this nest searching approach for Eurasian bitterns in the United Kingdom, use of foraging flights to detect nests have proven less effective for the same species in France and Italy, even when nests were known to be present (Puglisi & Bretagnolle, 2005). It is possible that the occurrence of foraging flights for Eurasian bitterns is dependent on food availability and incubation stage (Puglisi & Bretagnolle, 2005; White *et al.*, 2006), therefore reducing its reliability as a means of detection unless these two factors are also understood.

The third approach involves following nesting females that have been fitted with radio transmitters. This approach has allowed researchers to find nests of least bitterns in western New York (Bogner & Baldassarre, 2002b). The objectives of their study were to determine the breeding habitat requirements and home range size of female bitterns, rather than to count breeding pairs (Bogner & Baldassarre, 2002a). However, the method still has potential for the latter. Unfortunately, this approach is intrusive and time consuming, and relies on the capture of female bitterns, meaning the use of telemetry devices is still subject to the limitations of capture methods (See section 2.3.1.3 Mark-recapture, below). An alternative, not reported with other bittern species, may be to listen for the unique call made by chicks in the nest (Plate 2.2). To date, two Australasian bittern nests have been found using this method at Lake Whatumā, Central Hawkes Bay (pers. obs.).

2.3.1.3 Mark-recapture (MR)

Marking and recapturing individuals (MR) is often used to measure survival rates, dispersal and reproductive success (Bibby *et al.*, 1992). MR can also be used to estimate population size because it allows estimation of the number of individuals not detected (Borchers *et al.*, 2002; Cooch & White, 2010). Here the term “mark” is used to mean individually identify, and “recapture” is the detection of animals that are individually identifiable. Traditionally, in the case of birds, this tends to mean physical capture, and then marking any individuals that have been caught in a way that is visible (e.g. banding). For these traditional MR methods there is an array of possible field and modelling approaches that can be used. For most species the choice of which MR approach to adopt will depend upon the likelihood of several assumptions being met during the course of the study (Bibby *et al.*, 1992). Examples of some of these assumptions include: a) whether the population is closed or open (are there births, deaths, immigration and emigration during the sampling period?); b) whether the probability of recapture is likely to change across sampling periods; and c) the effect marks may have on individual behaviours. Fortunately, several modelling and sampling approaches now exist that can be used in circumstances where these assumptions cannot be met (White & Burnham, 1999). However, for bitterns, as with many other cryptic species, the key factors currently limiting the use of MR is more fundamental, as the low detectability of these species mean that the challenge lies in being able to mark and recapture individuals in the first place.

Bitterns are difficult to physically find and capture. Teal (1989) trialled several capture methods on Australasian bitterns in Whangamarino wetland. He reports two captures using drop traps, and three captures made by firing a net gun from a helicopter. Unfortunately, both of the drop trap captures were only partially successful as one resulted in a bird escaping after capture, and the other led to the death of a bird post-capture as a result of stress and poor condition. Use of the net gun from a helicopter was more effective but Teal (1989) concludes that this method was too expensive and stressful for birds. All other methods trialled by Teal - drop traps, spotlighting, walkthrough traps and the use of a net-gun from the ground - did not result in captures.

Despite these technical and ethical challenges, there is scope for capturing Australasian bitterns as seven of the 12 bittern species have been successfully captured using methods not yet trialled here in New Zealand: Eurasian, Australasian, American, least, yellow, Schrenck’s, and cinnamon bitterns (Table 2.3). No information regarding capture could be found for the five remaining species (Table 2.3). Development of a capture method for Australasian bitterns would not only be useful for mark-recapture studies but could also provide information regarding breeding biology and breeding success (Puglisi & Bretagnolle, 2005).

Mistnetting is the technique most commonly used to capture bittern species, proving successful for six species: Eurasian, American, least, yellow, Schrenck's, and cinnamon bitterns (Table 2.3). Most of these studies lured bitterns into mistnets using the playback of calls (Gilbert *et al*., 2005; Puglisi & Bretagnolle, 2005; White *et al*., 2006). It is currently not known whether this would work for Australasian bitterns. Teal (1989) suggested that Australasian bitterns do respond to playback, but was unable to capture any birds using playback and mistnets. However, the exact method trialled by Teal (1989) is unclear, and response-rates of Eurasian bitterns to playback is known to be variable, with some authors stating that successful catches can take several patient hours (Gilbert *et al*., 2005). Response to playback could depend upon an individual bird's breeding status and location (with respect to the individual's territory). Therefore, more work may be required before conclusions can be drawn regarding the feasibility of playback (and mistnetting) for capturing Australasian bitterns. Internationally, bitterns have been captured using net guns (1/12 species), landing nets (2/12 species) and cage traps (2/12 species) (Table 2.3). American bitterns have been successfully lured into cage traps using a combination of playback and mirrors (Huschle *et al*., 2002); something that could also be explored for Australasian bitterns. Unfortunately, very few published sources report failed capture attempts, making it difficult to determine which methods have been most effective for each species.

Assuming Australasian bitterns can be captured, the low probability of visually detecting birds (due to their secretive nature and inaccessible habitats) creates challenges with redetecting birds (Gilbert *et al*., 1994; Gilbert *et al*., 2002; Terry *et al*., 2005). Marking methods, such as leg bands and wing tags, are less likely to be readable in dense reed beds and the process of capturing birds may make marked birds shy and more difficult to detect compared to unmarked birds.

Fortunately, the lack of a physical capture method, and visual recapture method does not prevent mark-recapture entirely. In reality, animals can be marked and re-captured in many ways. For example, Eurasian and least bitterns have been successfully marked/recaptured (Table 2.2) using two less intrusive tools, vocal individuality and use of radio transmitters. Both show some promise with regard to Australasian bitterns.

2.3.1.4 Mark-recapture – using vocal individuality

The first of these two tools, vocal individuality, involves recognising call characteristics that have a high probability of discriminating[†] or identifying[‡] individual birds (Peake *et al*., 1998). Birds can be recaptured by recording calls over multiple occasions and matching key call characteristics to re-identify each individual. This approach has been trialled on Eurasian bitterns and has proven useful for assessing survival and site fidelity (Gilbert *et al*., 1994; Puglisi & Adamo, 2004). For other cryptic species, vocal individuality has been used successfully to calibrate population estimates against indices of abundance (Peake & McGregor, 2001; Hoodless *et al*., 2008). This approach has the advantage that physical capture of individuals is not required. Vocal individuality has potential for use with Australasian bitterns because their booms are long-ranging, frequent and distinctive, allowing calls to be easily recorded without needing to access all areas of the habitat, or causing disturbance and behavioural changes of birds (Teal, 1989; Terry *et al*., 2005; Rognan *et al*., 2009). This potentially solves most challenges associated with the spatial, behavioural and visual crypsis of this species (Chapter 1). Hoodless *et al*. (2008) reported that, for woodcocks (*Scolopax rusticola*), vocal individuality proved as informative as radio tracking with regard to the relationship between the number of calling individuals and number of calls, but had a much smaller impact on natural behaviours and lower risk to the bird (Hoodless *et al*., 2008; Rognan

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[†] ‘Discrimination’ is the ability to tell that two separate calls produced at roughly the same time were by different individuals. This is easier to do, in comparison with identification, because it is achievable even if call characteristics change across time. Discrimination is useful in terms of obtaining numbers of birds calling at any one time in the wetland (Peake *et al.*, 1998)

[‡] 'Identification' is the ability to unequivocally say that a call is similar enough to be from the same individual as one previously recorded. Additionally to the uses of discrimination, identification has the potential to provide data regarding survival, home range and/or site fidelity (Peake *et al.*, 1998).

et al., 2009). There are five limitations of this method with regard to its use on Australasian bitterns:

Firstly, to determine if vocal individuality is actually feasible, a means of marking individuals that is independent of their calls is required (Sutherland *et al*., 2004; Terry *et al*., 2005). This is important for being able to show that call characteristics from individuals are consistent and predictable over time (Terry & McGregor, 2002; Terry *et al*., 2005). As a result, the use of vocal individuality for bitterns is still to some extent limited by the lack of an effective capture method. Bittern researchers in the United Kingdom overcame this problem with Eurasian bitterns by making frequent visits to small wetlands and assuming that a consistently occupied territory indicates the same individual (Gilbert, 2006). Observations so far suggest that Australasian bitterns have high site fidelity and behave similarly to Eurasian bitterns during the breeding season (Chapter 6). Indeed, an Honours thesis on Australasian bitterns conducted in south-western Australia, using a similar approaches as European bittern researchers, suggested that Australasian bitterns are vocally distinguishable within short time-frames (Graff, 2014). However, the methods used in Graff (2014) are limited for census work because they rely upon prior knowledge of how many birds are in the population.

The second limitation is that, unlike physical capture methods, vocal individuality alone cannot provide any additional information regarding the state of the population, such as age structure, physical condition and breeding status (Rognan *et al*., 2009). Although this limitation has little effect on the method as a monitoring method, it restricts our ability to overcome some of the knowledge gaps regarding this species and to verify certain assumptions, such as the assumption that only males produce booming calls.

The third limitation is that the ability to differentiate between individuals reliably may change with bittern population size (Gilbert *et al*., 1994). This is because the possible combinations of call characteristics are usually finite, meaning that the probability of finding two individuals that cannot be distinguished will increase with population size (Budka *et al*., 2015). Despite this, Terry *et al*. (2002) notes that if a population census is desired, additional information can be collected to help narrow the number of comparisons required to discriminate/identify an individual. For example, recording the time of call and the bird's location can eliminate the need to compare birds that are simultaneously calling and/or are too far apart to be the same individual.

The fourth limitation is that, like acoustic triangulation, vocal individuality is biased toward the most vocally active proportion of the population (Terry *et al*., 2005), which for bitterns is adult males. The final limitation is that multiple, high-quality, close recordings are required for each individual bird (Gilbert *et al*., 1994). This is laborious, time consuming and requires sophisticated, sensitive equipment, which is also expensive. The time-frame for making repeat recordings is restricted to the breeding season when bitterns are booming and remain site loyal, limiting the feasibility of this monitoring option on a national level. To be achievable on a national scale, hundreds of recording units would be required, which would be expensive.

2.3.1.5 Mark-recapture using transmitters

The problem of not being able to 'mark' or 'recapture' bitterns can be solved by attaching devices to birds (e.g. radio transmitters), allowing remote detection. This of course assumes that they can be captured in the first place. Telemetry devices then allow individuals to be re-found and identified via their radio frequencies. Unfortunately, unlike vocal individuality, use of transmitters as part of MR does not provide any information about unmarked individuals during recapture occasions, limiting its use in determining the number of birds not caught. For example, with MR, marked individuals should not have a higher detectability compared with unmarked individuals. This assumption becomes invalid if bitterns wearing transmitters are detected and identified using the transmitter. However, it could prove useful if used in combination with other detection techniques. For example, detecting male bitterns by listening for booming calls and then identifying whether or not the booming bird is a 'marked' individual by listening to see if it is carrying a radio transmitter.

Table 2.3. Capture methods used for all 12 Botaurinae species. Symbols represent a subjective assessment of the effectiveness of a method: an effective method (✓) was one informative in terms of the objectives; an ineffective method (✗) was uninformative in terms of objectives; and an ambiguous method (?) presented information that conflicted with other studies or was incomplete. Blanks cells indicate no information could be found. Numbers link to the references of each assessment symbol, which can be found in the last column.

	Capture method used (✓ = Effective; ✗ = Ineffective; ? = Effectiveness not known)										
Species	Nestling capture	Walkthrough trap	Night capture	Spotlight	Drop trap	Funnel traps	Net gun	Landing nets	Mist nets	Mirror traps	References
Botaurus											
Eurasian bittern								✓[1]	✓[2]		[1] Puglisi *et al.*, (2001); [2] Gilbert *et al.*, (2005)
Australasian bittern	?[3]	✗[3]		✗[3]	?[3]		✗[3]		✗[3]		[3] Teal (1989)
American bittern			?[4]			?[4]	?[4]	✓[4]	✓[4]	✓[4]	[4] Huschle *et al.*, (2002)
South American bittern											
Ixobrychus											
Least bittern	✓[5]								✓[6]		[5] Bogner & Baldassarre (2002a); [6] Bogner & Baldassarre (2002b)
Yellow bittern									✓[7,8]		[7] Lansdown & Rajanathan (1993);[8] Zakaria & Rajpar (2010)
Stripe-backed bittern											
Schrenck's bittern									✓[9]		[9] Zakaria & Rajpar (2010)
Black bittern											
Little bittern											
Cinnamon bittern									✓[10,11]		[10] Lansdown & Rajanathan (1993);[11] Zakaria & Rajpar (2010)
Dwarf bittern											

2.3.2 Indices - Incomplete counts not corrected for detection

Estimating detection probabilities using incomplete count methods corrected for detection is expensive, takes time, and requires expertise; particularly when the use of these methods is complicated by species-specific cryptic characteristics (Thompson, 2004). Often in these circumstances it is easier and cheaper to rely on indices instead. This is especially the case when ambiguity exists regarding the underlying assumptions of incomplete counts (Thompson, 2004). Caughley (1977) argues that the majority of conservation monitoring problems can be solved with indices. Three methods already in use for bittern species that can be considered as indices include: best guess, call-counts and territory-mapping (Table 2.2).

2.3.2.1 Best guess/expert opinion

In circumstances where no count data are available, and data may be impractical to collect, population numbers are often assessed using best guess or expert opinion (Caughley, 1977). Population assessments for eight of the 12 bittern species have relied upon best guess at some stage (Table 2.2). These represent crude population measures that are often useful for identifying sites of further conservation interest and justifying the development of more structured monitoring protocols (Caughley, 1977). Best guesses are also sometime presented with false precision. For example, the best guess for the Australasian bittern population in 1980 was 580-725 (Heather & Robertson, 1996), a very precise measure for a species that is a challenge to detect, at a time when no official monitoring was conducted. Population assessments for three bittern species, the South American, stripe-backed and black bittern, seem to be reliant upon best guess alone, as no further studies appear to have been published (Table 2.2).

2.3.2.2 Call-counts

The majority of monitoring programmes for bittern species are based on index call-counts (Table 2.2). Typically, these involve counting as many species and individuals as possible, using one or more observers, within a designated area (e.g. multi-species bird counts). They are usually conducted by walking transects or by boat, visually looking for birds with the aid of binoculars and identifying any calls heard. Resultant data are useful to determine occupancy (presence of a bittern species) and relative frequency of detection among sites, but the reliability of inferences depends upon factors such as, sample size, how standardised successive surveys are, observer skills and the conspicuousness of the species at the time of the survey. As a result, data are likely to be imprecise and inaccurate, leading to underestimates of cryptic species such as bitterns (Gibbs & Melvin, 1993; Laurent *et al*., 2012).

Some species, such as the American bittern and the least bittern, are monitored as part of continental multispecies monitoring programmes, such as the North American Breeding Bird Survey (BBS) and Christmas Bird Survey (CBS). These are standardised to reduce some biases, such as certain weather variables and variability in conspicuousness at particular times of the day and year (Robbins, 1986). However, these surveys also fail to solve many of the restrictions and biases commonly associated with cryptic species (Table 1.1, Chapter 1). For example, BBS surveys take place along accessible roadsides (Robbins, 1986; Sauer *et al*., 1994), leaving this method more vulnerable to locational biases than a method that is based on random sampling (Gibbs & Melvin, 1997; Hutto & Young, 2002). Often, publications reporting results from these methods either completely exclude bittern species from analysis due to an insufficient number of detections, or conclude that results are uninformative beyond basic occupancy for bitterns (Robbins, 1986; Fleury & Sherry, 1995).

To address this problem, Conway (2009) developed a standardised protocol specifically targeting cryptic wetland species, such as rails, grebes and bitterns. This method uses call-broadcasting to increase detectability. Responses appear successful for many rail species, but were not consistent across studies for American and least bitterns (Table 2.2). Some papers report increased detectability via call broadcasting, whereas others show a decrease in detection or were unable to draw firm conclusions (Gibbs & Melvin, 1993, 1997; Ribic *et al.*, 1999; Bogner & Baldassarre, 2002b; Lor & Malecki, 2002; Allen *et al.*, 2004; Rehm & Baldassarre, 2007; Nadeau *et al.*, 2008; Budd & Krementz, 2010; Conway & Nadeau, 2010). Despite this, the method allows for the standardisation of weather variables and makes recommendations regarding the optimum time of day and year for sampling (Laurent *et al*., 2012). Also, the method is amenable to the estimation of birds not detected through techniques such as distance sampling (Farnsworth *et al.*, 2002; Allen *et al.*, 2004; Conway, 2009). Gibbs and Melvin (1993) warn against the use of distance sampling in conjunction with call broadcasting, as broadcasting calls can cause birds to move towards or away from observers before they are detected. To reduce any bias associated with this, protocols recommend that point counts are conducted at survey points before broadcasting takes place. This enables separate analysis of data with and without the use of broadcasting, and the ability to quantify the effect of call-broadcasting (Conway & Nadeau, 2010). Another solution is to quantify the attraction of call broadcasting on birds using birds marked with telemetry gear. However, this also requires being able to capture birds (See 2.3.1.3 Mark-recapture, above).

2.3.2.3 Territory-mapping

Territory-mapping can also be useful as an index of abundance if the assumptions of this method as an incomplete count corrected for detectability are violated (section 2.3.1.1). For example, the assumption that bitterns can be accurately located, and are site loyal (assumptions three and five; section 2.3.1.1), are only necessary if birds need to be identified by their location across time. If these assumptions cannot be met, the same data can be used as an index of abundance provided observers were competent at recognising bittern calls, surveys were conducted under standardised conditions, and factors such as probability of detecting a territory (PDT) and the number of birds double counted remain consistent between sampling periods (assumptions one, four, six and seven). Furthermore, the process of triangulating bitterns helps observers to distinguish between individual calling birds during surveys as it allows the development of a clear, concise rule-based criteria that observers can use to decide if calls are from different birds. For example, a new call can be classed as having been produced by the same individual as a previous call if distance is the same and any bearing differences are less than 10 degrees (Pierce, 2004; Holzapfel, 2006). Having rule based criteria is likely to produce counts of bitterns that are more accurate and informative compared to indices that rely on calling-rate alone, provided that the density of the bittern population is not so high that observers are unable to record and process all calls from all birds. A key disadvantage is that territory-mapping (even as an index method) is inefficient in terms of time and effort due to the number of observers and repeat visits required (Bibby *et al*., 1992). When considering whether or not to use territory-mapping for a specific study, this extra effort and use of resources would need to be justified in relation to the study objectives. When all assumptions can be met, acoustic triangulation as an incomplete count corrected for detectability can deliver population estimates that have a level of accuracy and precision that is measurable in terms of bearing error (Lefebvre & Poulin, 2003). Furthermore, observers require little equipment and training to be proficient at acoustic triangulation, creating potential for the use of this method on a national level, and by multiple organisations.

2.3.3 Occupancy

Occupancy is the presence/absence of a species within a defined sampling area, where a sampling area can either be a grid cell or a naturally defined section of habitat (e.g., a forest fragment or pond) (Thompson, 2004). Occupancy has only been used for one bittern species, the Eurasian bittern (Gilbert *et al.*, 2007). For the Eurasian bittern, the proportion of sites occupied by booming males, that also had nesting females, was used (in part) to make inferences about breeding biology (Gilbert *et al.*, 2007). Occupancy is particularly attractive in the case of cryptic species because repeated sampling of areas allows calculation of the probability of detection. Also, in the case of occupancy, only one animal of a species needs to be detected for each area. This reduces the need to access all areas of a site and allows the use of sampling procedures that are less intrusive and inexpensive compared to abundance estimation. This provides greater potential to solve many of the sampling restrictions associated with cryptic species (Chapter 1). As such, occupancy can be used to measure spatial population trends where abundance estimation is unsuitable (Thompson, 2004). However, inferences based on occupancy are not the same as abundance because a change in the spatial distribution of a species does not necessarily relate to a change in population size. The spatial distribution of a species will be affected by the mobility and spatial behaviours of that species (Mackenzie & Royle, 2005). Therefore, the appropriate use of occupancy as a surrogate for abundance can only be judged in terms of a project's specific objectives and expert knowledge of target species behaviours. Despite this, the probability of detecting one or more animals within an area will also be related to abundance, providing scope for one to be used to estimate the other (Thompson, 2004; Royle & Link, 2005).

As with abundance, the ability to determine species occupancy depends upon several environmental and biological factors. Therefore, detection probabilities must also be taken into consideration (Crossland *et al.*, 2005; Mackenzie & Royle, 2005). To do this, searches of sampling areas are repeated over a relatively short time-frame, during which time, true occupancy is expected to remain constant (Thompson, 2004). It is this spatial and temporal replication that allows separate calculation of the probability of occupancy and detection (MacKenzie, 2005; Bailey *et al.*, 2007).

Occupancy has the potential to produce unbiased estimates, with a relatively low sampling effort, and has proven useful as a monitoring method for cryptic Hochstetter's frogs (*Leiopelma hochstetteri*) (Crossland *et al.*, 2005). Hochstetter's frogs are cryptic because they are small, have an inconspicuous colouration, are well hidden (visually cryptic), and sparsely distributed (behaviourally cryptic) (Crossland *et al.*, 2005). In this example, capture-mark-recapture is particularly challenging as frogs often inhabit crevices, tunnels and fissures; where they can be seen but cannot be captured (spatially cryptic) (Crossland *et al.*, 2005). Occupancy modelling overcomes these difficulties because the presence of a species can be confirmed much less intrusively and intensively compared to the collection of data for abundance (MacKenzie, 2005; MacKenzie *et al.*, 2005).

For Australasian bitterns, occupancy provides scope to monitor populations on a national scale because of the low survey intensity required. Monitoring on a national scale would be preferable, when feasible, because national declines may not be well represented on a local scale (Alford & Richards, 1999; Crossland *et al.*, 2005). Occupancy can be calculated for a single season provided the following four assumptions are reasonable (MacKenzie *et al.*, 2002). Firstly, the occupancy state must remain constant during a sampling period, allowing extinction and recolonisation to be modelled between periods. Secondly, the species must not be falsely detected in an area where it is not present. Options exist for situations where either of these assumptions are violated (MacKenzie *et al.*, 2003; Royle & Link, 2006) but, in the case of male Australasian bitterns, both assumptions should be reasonable during the breeding season, when male bitterns produce their distinct booming call from relatively stable locations (Teal, 1989; Pierce, 2004).

The third assumption is that all sources of variability in detection are modelled, so that the probability of detection, calculated from sites where the species was detected, can be reasonably applied to sites where the species was not detected (MacKenzie *et al.*, 2002). There is currently a deficit of information regarding factors that affect the calling rate of Australasian bitterns, so more information is required in this area (Chapter 3).

The final assumption is that the detection of a species at any site is independent of detections at other sites. The validity of this assumption will depend upon the appropriateness of the scale of sampling (MacKenzie, 2005). For small isolated wetlands this assumption is likely to be valid provided bitterns do not move long distances within a short space of time, something that is not known for Australasian bitterns. For large, high-density wetlands, this assumption is unlikely to be met because booms of this species are thought to be heard up to 4 km away (Teal, 1989). Under these circumstances, sampling grids of <4 km would result in the same birds being counted across multiple samples. This will give the appearance of having large sample sizes and precise estimates when in fact data are pseudo-replicated (Thompson, 2004). Occupancy estimates based on grids >4 km may not have a high enough resolution to be informative with regard to population declines. One solution here may be to set the scale of sampling to > 4km but increase the resolution by counting the number of individuals detected in each grid across multiple visits instead of only recording the presence/absence of a species. According to Royle and Link (2005), data can then be modelled to estimate the probability of observing each possible index value at a given time and site, considering the maximum index value that was observed for that site across the entire study period. For example, where a maximum index value of 4 is observed, values of 0, 1, 2, 3 or 4 could be expected from any particular visit to that area. The distribution of these probabilities among sites provides an ‘average latent abundance value’, which can be used as an index of calling-rate that has been corrected for non-availability and variable probabilities of detection. Royle and Link (2005) used this method to model the latent abundance classes of anuran populations. To do this, they grouped frog calling-rates for each visit into four abundance classes: no frogs heard (y = 0); discrete, non-overlapping calls (y = 1); discrete, overlapping calls (y = 2); and continuous, overlapping calls (y = 3). Their model assumes that the maximum calling-index value (a hidden value) is estimable from calling-rate and related to population size (the desired parameter). Such techniques may also be useful for bitterns where use of occupancy is likely to be insensitive to population changes and abundance cannot be directly estimated.

2.4 Alternative cue detection methods

The majority of methods used on bittern species involve visually finding birds (or nests) or detecting birds via their calls. However, a review of 30 publications, covering 28 different species with similar cryptic problems to bitterns (Chapter 1) showed that several of these species are monitored using alternative cues that may also be applicable to bitterns. In particular these include detections via scent, heat or movement.

2.4.1 Detections via scent (use of dogs)

Trained scenting dogs have been used to detect a variety of olfactory cues, including: drugs, explosives, flammable chemicals, toxins, human scents, cancerous cells, and a range of plant and animal odours (Browne *et al*., 2006). The ability of dogs to detect individual animals, or the signs of animals, has proven useful for assessing population status, threats, trends, age structure, and as part of an advance warning for pest management and biosecurity (Brooks *et al*., 2003; Robertson & Fraser, 2009). A range of published examples exist that highlight the potential of scent-dogs as a tool for overcoming multiple restrictions commonly associated with cryptic species (Table1.1; Chapter 1); in particular species that are nocturnal, well camouflaged, well hidden, inactive, and patchily distributed, such as: yellow rails (*Coturnicops noveboracensis*), bumblebees (*Bombus spp.*), brown treesnakes (*Boiga irregularis*), Mojave desert tortoises (*Gopherus agassizii*), San Joaquin kit foxes (*Vulpes macrotis mutica*) and termites (*Reticulitermes spp., Coptotermes spp., and Heterotermes spp.*) (Zwickel, 1980;

Robert & Laporte, 1997; Brooks *et al*., 2003; Smith *et al*., 2003; Cablk *et al*., 2008; Waters *et al*., 2010; Savidge *et al*., 2011).

Used appropriately, scent-dogs can reduce on-going monitoring costs, human labour, and human biases; whilst increasing sample sizes (Zwickel, 1980; Robertson & Fraser, 2009). In general, scent-dogs are considered to be easy and cost effective to train (Castelli & Sleggs, 2000; Browne *et al*., 2006), although, some contradictory examples exist (O'Connor *et al*., 2012). In many cases, scent-dogs provide a means of detecting animals that is not biased toward any particular age, sex or size (Cablk *et al*., 2008; Robertson & Fraser, 2009). This is of particular interest with regard to Australasian bitterns as auditory monitoring methods only provide information regarding the adult male bittern population, and there is a deficit of options that target females and juveniles. Similarly bittern scent should be detectable all year round, which may relieve some of the constraints caused by the short-window that is available for detection of booming bitterns.

Despite these benefits, detection of bitterns using scent-dogs still has limitations. For example, a dog's ability to detect bittern scent is likely to be influenced by factors such as dog/handler experience, dog age, time of day, environmental conditions, vegetation density (restricting scent movement), presence of other strong scents, water depth (restricting access) and the health of the dog (Gutzwiller, 1990; Smith *et al*., 2003; Arnett, 2006). Distance estimation is known to be problematic as environmental factors complicate scent dispersion, and the area covered will depend on the dog's movements, something that is not easily measurable without global positioning systems (Cablk *et al*., 2008; Reed *et al*., 2011; Savidge *et al*., 2011). Despite this, these potential biases also exist when monitoring populations via auditory cues.

There are several types of working scent-dog; some specialise in detecting scents in the air, while others work with their noses down to detect scent on the ground. Similarly, different breeds communicate detections differently, with some species having a natural tendency to point while others flush. For monitoring bitterns, an air-scenting dog would probably be the most useful as these typically work down-wind of the targeted area searching for scent with their heads up. Scent is thought to disperse away from its source in a plumb or cone shape (Cablk *et al*., 2008). Therefore, when an air-scenting dog finds scent it will work into the scent-cone until it can locate the source. This technique would suit monitoring for bitterns as it allows individuals to be detected from a distance, potentially overcoming access restrictions and reducing disturbances to individual birds (Zwickel, 1980). Another possibility may be to employ a pointer dog along accessible transects and use the number of indications as an index of abundance.

2.4.2 Detections via infra-red or motion (use of cameras)

Infrared/motion cameras have already shown potential for the thermal detection of some large cryptic species such as tigers, snow leopards, Florida Key deer (*Odocoileus virginianus clavium*) and Sumatran ground cuckoos (Swann *et al*., 2004; Jackson *et al*., 2006; Dinata *et al*., 2008; McCarthy *et al*., 2008; Watts *et al*., 2008; Barlow *et al*., 2009). Unfortunately, camera trapping methods used for these species currently provide little potential for the Australasian bittern. This is because these methods passively exploit predictable behavioural traits, such as the regular use of tracks, marking sites, or the species' attraction to lures. Predictable behaviours that can be exploited in this way have yet to been identified for bitterns. However, preliminary attempts at placing trail cams along tracks through the raupō at Lake Whatumā in 2014, have proven successful, occasionally capturing images of bitterns (Plate 2.1).

Additionally, several motion and heat sensor options exist that do not rely as heavily on predictable behavioural traits. For example, thermal satellite imagery was being used to detect phytoplankton as early as the 1980s (Fiedler & Bernard, 1987). More recently, ground-based thermal imagery has been used to successfully detect white-tailed deer fawns (*Odocoileus virginianus*) (Ditchkoff *et al*., 2005), and aerial thermal imagery has proven useful for detecting deer (*Odocoileus virginianus*) and panthers (*Puma concolor*) (Havens & Sharp, 1998). As thermal and motion sensing technology improves, these options may become more affordable, and therefore feasible as options for cryptic species. This is particularly likely for cryptic species that are comparatively large in size, such as Australasian bitterns.

2.5 Conclusions and recommendations

Monitoring is problematic for all bittern species, leading to a heavy reliance on index methods for these species. Australasian bitterns in particular have all four cryptic categories that are associated with a species that is difficult to detect (visual, behavioural, temporal and spatial crypsis). Dense vegetation and the secretive nature of the species prevents the use of any visually reliant methods (territory-mapping using sightings, and traditional mark-recapture). As a result, monitoring methods that depend upon non-visual cues are needed for this species. The booming call produced by males during the breeding season is currently the most feasible cue available for detection of Australasian bitterns. This is because calls are distinct and far reaching. However, because calling rates of this species are known to be variable, we need more information about factors that cause this variability before any of these methods can be relied upon. Of the methods previously used on other bittern species, all eight methods have some potential to be used for Australasian bitterns but require more research to validate method assumptions or solve sampling restrictions (Table 2.4). In particular, two research questions, and one task, emerged as important for further attention as they provide the greatest potential for developing of a suite of monitoring methods (Table 2.5). These are as follows:

1) Is calling rate predictable? (Chapter 3)

2) Do bitterns have high site fidelity during the breeding season? (Chapter 6)

3) Development of a capture method (Chapter 6 – in part)

Assuming these questions/tasks can be addressed, three additional questions emerge as important. Answers to these questions, combined with the information obtained above, allow the development of two incomplete count methods corrected for detectability (territory-mapping using acoustic triangulation and territory-mapping using close approaches), one incomplete count method that is not corrected for detectability (call-counts per unit time) and a mark-recapture method (mark-recapture using transmitters) (Table 2.5). These three additional questions are as follows:

1) Are male territories distinct? (Close approaches and acoustic triangulation, Chapter 6)

2) Does bearing error influence estimates from acoustic triangulation? (Acoustic triangulation, Chapter 6 in part)

3) Can call-rate be used to indicate changes in abundance? (Call-counts per unit time, Chapter 5)

It is important to be aware that call-reliant options will be limited for bitterns because they provide no information about females or juveniles, and use is restricted to the breeding season. If information is required on females and juveniles, alternative options need to be developed (Discussion, Chapter 7).

Table 2.4. Summary monitoring options feasible for Australasian bitterns. Feasibility is based on work done on related species. Symbols denote whether assumptions are likely to be reasonable for Australasian bitterns, where: ✓ = assumptions reasonable; ✗ = assumption likely to be violated; ? = work required to confirm reasonableness of assumptions. Where more work is required this is summarised in the column to the right

Incomplete counts corrected for detectability			
Method	Assumptions	Feasibility	Work required
Territory-mapping - calls/sightings	1) Observers are competent at locating and identifying birds	1) ✓	1) None
	2) Individual birds must be well spaced with no overlap between territories	2) ?	2) Confirm territories are distinct (Chapter 6)
	3) Individual birds must have high site fidelity throughout the sampling period	3) ?	3) Confirm males have site fidelity (Chapter 6)
	4) The probability of detecting each territory must be high	4) ?	4) Identify factors affecting call-rate (Chapter 3)
	5) Birds are located and mapped accurately	5) ✓$^{\text{Close approaches}}$?$^{\text{Acoustic triangulation}}$	5) None required for close approach methods Quantify bearing error
	6) Individual birds must not be double counted during each visit	6) ?	6) Confirm males have site fidelity (Chapter 6)
	7) Sampling is standardised as much as possible to limit bias from factors such as weather conditions, time of day and number of visits	7) ?	7) Identify factors affecting call-rate (Chapter 3)
Territory-mapping - nests	1) Observers are competent at locating and identifying nests	1) ?	1) Identify cues to find nests
	2) The probability of detecting a nest must be high	2) ?	2) Identify cues to increase detectability
	3) All nests are located and mapped accurately	3) ?	3) Identify factors that affect detectability of nests
	4) Effort is standardised between sampling occasions	4) ✓	4) None
Mark-recapture (Traditional)	1) Animals can be physically captured and marked	1) ?	1) Development of a capture method (Chapter 6)
	2) The state of the population is known e.g. closed or open	2) ?	2) Confirm study site fidelity (Chapter 6)
	3) The probability of recapture does not change	3) ?	3) Confirm bitterns can be recaptured
	4) Marks are not lost and any effect of marking on behaviours is measurable	4) ✓	4) Confirm assumption
Mark-recapture (Vocal individuality)	1) Animals can be captured (physical and non-physical) and marked	1) ✓$^{\text{capture}}$?$^{\text{Identify}}$	1) Confirm birds identifiable via calls (capture desirable)
	2) The state of the population is known e.g. closed or open	2) ?	2) Confirm study site fidelity (Chapter 6)
	3) The probability of recapture does not change	3) ✓	3) None
	4) Marks are not lost and any effect of marking on behaviours is measurable	4) ✓	4) None
Mark-recapture (Using transmitters)	1) Animals can be physically captured and marked	1) ?$^{\text{capture}}$✓$^{\text{identify}}$	1) Development of a capture method (Chapter 6)
	2) The state of the population is known e.g. closed or open	2) ✓	2) None proposed
	3) The probability of recapture does not change	3) ✗$^{\text{find via transmitter}}$ ✓$^{\text{find via boom}}$	3) Do not use
	4) Marks are not lost and any effect of marking on behaviours is measurable	4) ✓	4) None – assumption is reasonable

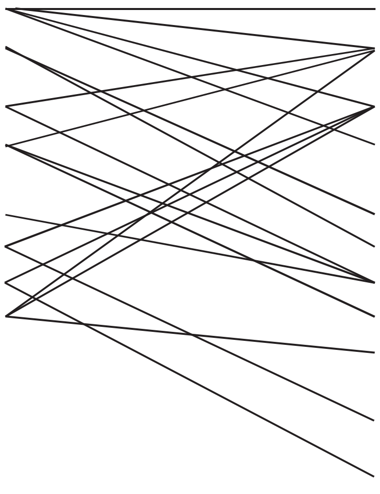
Indices - Incomplete counts not corrected for detection

Method	Assumptions	Feasibility	Work required
Best guess/ expert opinion	1) Guess relates to actual numbers	1) ?	1) Do not use long term
Call-counts	1) Observers are competent at identifying and recording calls	1) ✓	1) N/A
	2) Detection rates are sufficient to prevent zero inflation	2) ?	2) Identify factors affecting call-rate (Chapter 3)
	3) Changes in call-rate reflect changes in abundance	3) ?	3) Is call-rate indicative of abundance (Chapter 5)
	4) Sampling is standardised as much as possible to limit bias from factors such as weather conditions, time of day and number of visits	4) ?	4) Identify factors affecting call-rate (Chapter 3)
Territory-mapping	1) Observers are competent at identifying birds	1) ✓	1) N/A
	2) Detection rates are sufficient to prevent zero inflation	2) ?	2) Identify factors affecting call-rate (Chapter 3)
	3) Individual birds can be distinguished using a rule based criteria	3) ?	3) Confirm rule based criteria are valid
	4) Double counting and detection probabilities remain constant between visits	4) ?	4) Identify factors affecting call-rate (Chapter 3)
	5) Sampling is standardised as much as possible to limit bias from factors such as weather conditions, time of day and number of visits	5) ?	5) Identify factors affecting call-rate (Chapter 3)

Occupancy

Method	Assumptions	Feasibility	Work required
Occupancy	1) True occupancy remains constant during sampling periods	1) ?	1) Confirm study site fidelity (Chapter 6)
	2) The species must not be falsely detected in an area where it is not present	2) ✓	2) N/A
	3) All sources of variability in detection are modelled	3) ?	3) Identify factors affecting call-rate (Chapter 3)
	4) Detection of a species at any site is independent of detections at other sites	4) ×	4) Investigate methods where modelling can account for this violation e.g Royle and Link (2005)

Table 2.5. Research questions associated with each method. The column 'Questions to method' shows the number of research questions that need to be addressed for each method and the column 'Methods to question' shows the number of methods that can be developed further with each research question.



Method	Questions to method	Research questions	Methods to question
Territory-mapping - calls/sightings	4	Are male territories distinct?	1
Territory-mapping - nests	2	Do males have high site fidelity during the breeding season?	4
Mark-recapture (Traditional)	2	Is calling rate predictable?	4
Mark-recapture (Vocal individuality)	3	Does bearing error influence estimates from acoustic triangulation?	1
Mark-recapture (Using transmitters)	1	Can we find nests?	1
Call-counts	2	Is nest finding a reliable tool?	1
Territory-mapping (index)	2	Can bitterns be captured and recaptured?	3
Occupancy	3	Can individual bitterns be identified via their calls?	1
		Can modelling be used to solve assumption violations?	1
		Can call-rate be used to indicate changes in abundance?	1
		Is a rule based criteria for distinguishing individuals reasonable?	1

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3

Modelling variation in call-rates to develop a reliable monitoring method for a cryptic wetland species, the Australasian bittern

The cryptic fernbird, an inhabitant of dense scrublands and wetlands in New Zealand. Credit: Adrienne Grant.

3.1 Introduction

Species that are rare and difficult to detect (here after referred to as 'cryptic') are particularly challenging to monitor (Thompson, 2004). As complete counts are rarely feasible even with the most gregarious of species (Thompson *et al.*, 1998), monitoring practises for cryptic species inevitably involve counting cues, such as scats or calls (incomplete counts). This can be problematic because cue production is often influenced by unidentified covariates that act independently to the density of the species (Williams *et al.*, 2002). Failing to identify and account for these covariates would result in measures that are imprecise and can, in extreme cases, create situations where population trends are obscured or misleading (e.g. examples in Clarke *et al.*, 2003).

The Australasian bittern, *Botaurus poiciloptilus,* is an endangered cryptic wetland bird occurring in New Zealand, New Caledonia and Australia (BirdLife International, 2014). Bitterns present an appropriate case study as a cryptic species, because their plumage makes them difficult to see in their environment, and large areas of their habitat are inaccessible, restricting standard sampling practises at many sites. Additionally, previous attempts to capture bitterns have been largely unsuccessful suggesting methods such as capture-recapture are not feasible, particularly at large, inaccessible sites (Teal, 1989). Yet, conservation managers are interested in identifying the causes of decline of bitterns so that key habitats can be managed to reverse population declines (Kushlan, 2007; O'Donnell, 2011).

Male Australasian bitterns produce a 'booming' call during the breeding season, which is thought to be associated with territory defence and mate attraction (Teal, 1989). This booming call is far reaching and distinct, and therefore lends itself as a potential 'cue' for monitoring the species (Marchant & Higgins, 1990). Unfortunately calling-rates of this species are also known to be variable. For example, at a single listening post at Whangamarino wetland, Waikato, New Zealand, the number of call sequences heard per 15 min can vary from zero to fifty within a single breeding season (pers. obs.). Reasons for this variability are not clear, but previous work on Australasian bitterns suggests that time of day, time of month and moon phase could influence calling-rates (Teal, 1989). Similar studies of closely related bittern species suggest calling-rates could be affected by time of day, temperature, rain and cloud cover (Palmer, 1962; Puglisi *et al.*, 1997; Poulin & Lefebvre, 2003a).

Such high variability in calling-rates confounds interpretation of call-count data by obscuring trends and reducing the power of call-based methods to show population trends across time (Clarke *et al.*, 2003). This reduction in power could be alleviated by monitoring over longer time frames or through increased sample sizes. However, in the case of the Australasian bittern, a species that is already endangered, has multiple potential threats, and inhabits areas that are already challenging to access, such luxuries may be ill afforded. Instead it is preferable to reduce this variability by standardising and optimising monitoring practises rather than statistically adjusting for it by attempting to increase survey effort. A variable calling-rate would not necessarily be a problem for managers provided that the causes of variability are predictable and measurable (Williams *et al.*, 2002; Johnson, 2008a).

The aims of this chapter are to: 1) investigate which factors influence the calling-rate of male Australasian bitterns, and 2) quantify the effects of those factors in order to standardise call-based monitoring for Australasian bitterns. Having a greater understanding of factors that influence calling-rates and the size of these effects will allow managers to take into account variables that could obscure population estimates, potentially improving indices of population change, and allowing correct identification of the status of this species. As such, this research is an important part of the process of developing a call-count index method that can be interpreted meaningfully in terms of abundance, occupancy and long-term trends (Thompson *et al.*, 1998; Lambert *et al.*, 2009; Lindenmayer *et al.*, 2012).

3.2 Methods

3.2.1 Study site

Whangamarino wetland (175°07'E,37°18'S), in the Waikato region, is situated 4.2 m above sea level, approximately half-way between Hamilton and Auckland, New Zealand. This bog/swamp complex covers 7100 ha, making it the second largest wetland in the North Island of New Zealand (Ogle & Cheyne, 1981; Clarkson *et al.*, 2004; Wildlands

Consultants, 2009). Whangamarino wetland has a temperate climate typical of the Waikato region, with an annual rainfall of 1200 mm, and mean daily temperatures ranging from 9°C in winter to 19°C in summer (Blyth, 2011). Wetland water levels rise and fall consistently between winter and summer, but usually peak June to November (Blyth, 2011), around the time of the bittern breeding season (O'Donnell, 2011).

3.2.2 Data collection

During 2009 and 2010, observers sat at individual fixed points (referred to as stations) listening for Australasian bitterns. Call-count periods lasted 15 min, after which the observer moved on to a consecutive station. Count duration was chosen because a pilot study indicated that 70% of calling bitterns were detected at a site within the first 15 min (O'Donnell *et al.*, 2013) and is similar to the 10 min duration used in European studies (Poulin & Lefebvre, 2003a, 2003b).

Initially, counts were conducted at 65 stations representative of Whangamarino wetland from 6 October to 20 November 2009. However, 10 of these stations were excluded because no bitterns were detected after multiple counts had been conducted (suggesting zero counts at these stations could be due to ‘absence’ rather than ‘non-detection’), and 14 could only be visited once due to logistical restrictions (meaning there were insufficient data to obtain a reliable maximum number of bitterns for these stations). Thirty-four of these stations were repeated in 2010 between 10 September and 26 November, along with five new stations (Figure 3.1). Stations were positioned ≥ 400 m apart in accessible areas of the wetland. In keeping with similar European studies, all 15 min counts were conducted within one of two daily observation periods designed to contain peak booming activity, each spanning five hours (03:00-08:00 including sunrise and 17:30-22:30 incorporating sunset)(Poulin & Lefebvre, 2003a, 2003b; Polak, 2006).

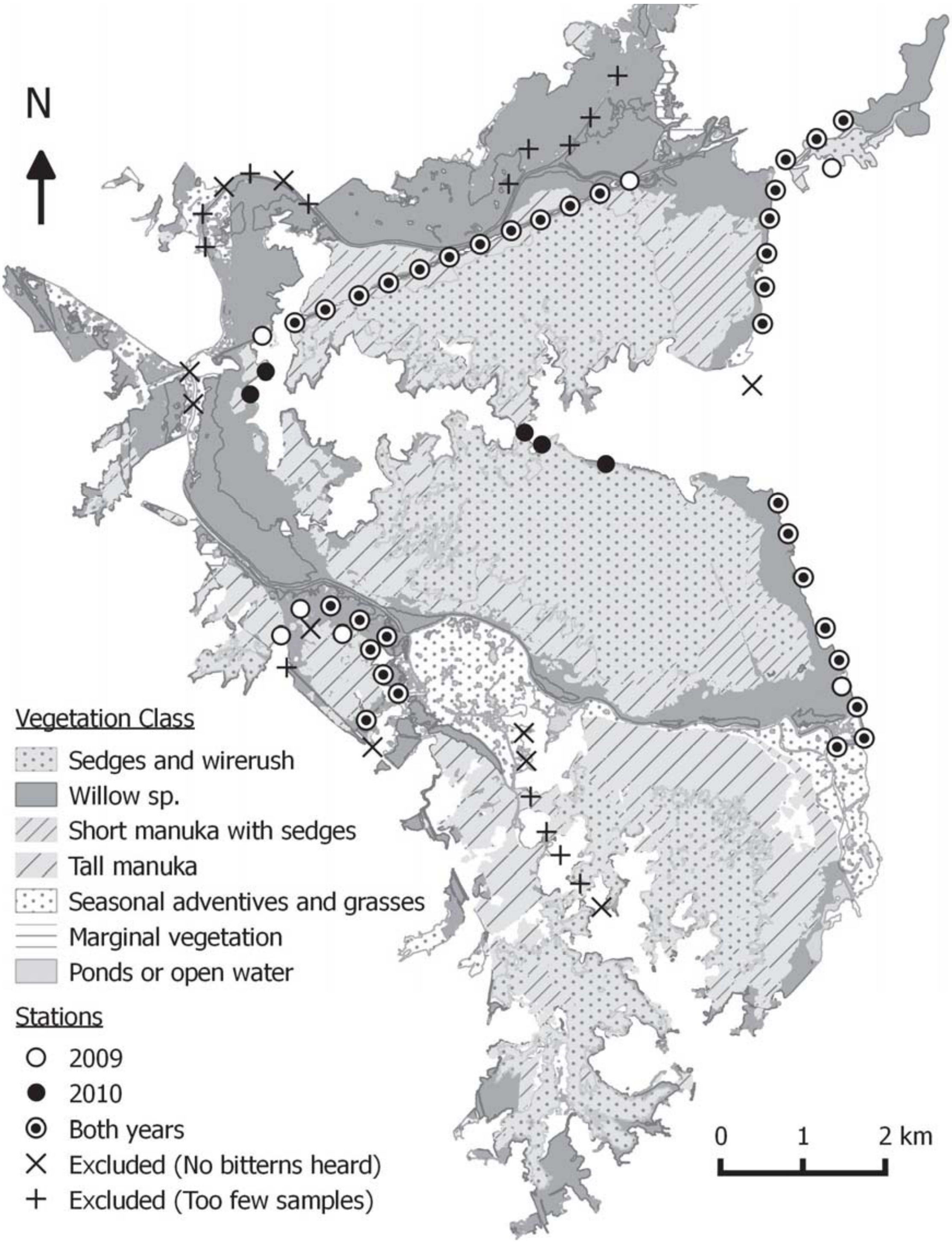

Figure 3.1: Locations (stations) of call-count listening stations at Whangamarino wetland for 2009 and 2010. Samples from some stations were excluded from analysis because no bitterns were heard or few samples (< 2) could be collected due to logistical reasons.

Overall, the 46 count locations that could be included were designed to represent the best coverage of the wetland possible given the logistical restraints in accessing many areas of the habitat. As a result, counting stations covered a mixture of areas with high and low bittern calling activity. Whangamarino wetland is so vast that it was impractical to survey stations in a random order. Instead, the first station surveyed per observation-period was randomised, and subsequent counts for that day were conducted at stations in close proximity to the starting station. Once all stations in an area had been surveyed, surveyors removed these stations from the randomised list and re-randomised the list ready for the next observation period. Once all stations had been done at least once they were added back in to the list and re-randomised, allowing the process to start again.

Observers noted all bittern call sequences heard during each count. At the end of each count, observers noted cloud cover in oktas and assigned an ordinal background noise category (Low/Med/High; Table 3.1; Appendix 2). In 2010, observers also made an assessment of the visibility of the moon during count periods (Table 3.1). Count periods were not conducted in heavy rain or strong winds.

Individual booming males could be discriminated (but not identified[1]), and therefore tallied, within a count period using a combination of call direction and call characteristics (call volume and number of booms in sequence). Each time a bittern was heard, observers made a judgment as to whether the call was from a new bird, or one that had been previously heard within the count period. A call-sequence was noted as being from a 'new' bird if any of the following was found to be true (Pierce, 2004):

- The bearing of the new call was greater than 10˚ different from the bearing of any call previously heard;
- The bearing of the new call was within 10˚ of another call but call volume was different; and

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[1] Note: Where, 'Discrimination' is the ability to tell that two separate calls were produced by different individuals, whilst 'Identification' is the ability to unequivocally say that a call is similar enough to be from the same individual as one previously recorded (Peake *et al.*, 1998).

- The bearing of the new call was within 10˚ of another call, but consistently has a different number of booms within its boom sequence compared to the previous call.

Weather variables were collected using a weather station located in Whangamarino wetland (175° 8.735'E, 37° 20.161'S). Readings for air temperature (^{o}C), rainfall (mm), wind speed (m/s) and water levels (m) were taken by the weather station every two min, and returned as an average across a 30 min period. In order to match these data with results from bittern call-counts, weather variables were represented as a mean value for each observation period.

Table 3.1: Explanatory variables considered for modelling the calling-rate per individual Australasian bitterns. Calling-rates were measured per 15 min count at Whangamarino wetland in 2009 and 2010.

Variable name		**Description**	**Relationship tested in Model M1**	**Value at Intercept**
mo	Month	0 = Sept; 1 = Oct; 2 = Nov	Categorical (fixed)	0 = September
TD	Time of day	27 15-min categories with categories 1-14 orientated in relation to sunrise (14) and categories 15-27 orientated in relation to sunset (13). Where category 1 represents 3:30 h before sunrise and category 15 represents 1 h and 44 min before sunset	Categorical (fixed)	1 = 3:30 h before sunrise
WL	Water levels	Water Levels over the 5-h observation period, with a range of 11.91 m to 10.26 m throughout the study period. Values scaled and centred using program R; $\mu = 11.20$; SD = 0.34	Linear (fixed)	Lowest water levels (10.26 m)
Rn	Rain	Average rainfall (mm) per 30 min over the 5-h observation period, ranging from 0 – 0.34 mm. Values scaled and centred in program R, $\mu = 0.01$; SD = 0.04	Linear (fixed)	No rain
cld	Cloud cover	Measured by a person in the field using the oktas system for aviation weather forecasts. Where, 0 = No cloud detected, 1 = 1 – 2 oktas, 2 = 3 – 4 oktas, 3 = 5 – 7 oktas and 4 = 8 oktas. Values constrained between 0 and 1.	Linear (fixed)	0 = No cloud
MPh	Moon phase	Number of days from full moon constrained as a value between 0 and 1, so full moon = 1, one day either side of full moon =0.93, two days either side = 0.87, 15 days either side = 0, and so on…	Linear (fixed)	15 days either side of full moon
MV	Moon visibility (measured in 2010 only)	1= Moon not visible, completely covered by clouds; 2= moon visible but mostly covered by cloud during the count; 3= moon visible but occasionally covered by cloud during the count; 4= moon visible throughout count. Values were constrained between 0 and 1.	Linear (fixed)	0 = Moon not visible, completely covered by clouds

Variable name		Description	Relationship tested in Model M1	Value at Intercept
int	Interactive term	Moon visibility*Moon phase, where Moon visibility was only measured in 2010	Linear (fixed)	Moon is 15 days either side of full moon (smallest in appearance) and completely covered by cloud
WS	Wind speed	Represents an average over the 5-h observation period (PID), ranging from 0.04 – 0.44 ms^{-1}. Values scaled and centred using program R; μ = 0.128; SD = 0.07	Linear (fixed)	Lowest value = 0.04 ms^{-1}
T	Temperature	Represents an average per observation period, ranging from 2.4 – 17.65 ^{o}C. Values scaled and centred using program R; μ = 11.104; SD = 2.74	Linear (fixed)	Lowest temp = 2.4 ^{o}C
Ns	Background noise	0 = Low; 1 = Medium; 2 = High	Linear (fixed)	0 = Low
yr	Year	0 = 2009; 1 = 2010	Linear (fixed)	0 = 2009
obs	Observer	Field observer (1 – 4)	Categorical (fixed)	Observer 1
PID	Observation period ID	Identifies each observation period, where an observation period is defined as the morning (3:00 – 8:00) or evening (17:30 – 22:30) on one day.	Random	Separate intercepts for each PID
stn	StationID	86 stations	Random	Separate intercepts for each station

3.2.3 Statistical Analysis

The response variable modelled was the number of call sequences heard in 15 minutes at a particular station and time. This number was assumed to be Poisson distributed around the expected number of call sequences, which was determined by the number of males present and the expected calling rate per individual (Equation 3.1).

Equation 3.1:

$$Y_{i,j} \sim Poisson(N_j \times CRPI)$$

Where, $Y_{i,j}$ is the number of call sequences at station *i* at time j, N_i is the number of males present and $CRPI_{i,j}$ is the expected calling rate per individual.

In this study, N_i was assumed to be known, and was given as the maximum number of bitterns that were counted (or discriminated) within a count period at each station over the whole season. This is a reasonable assumption because it is likely that all bitterns would have called during at least one of the multiple observation sessions conducted at each site, and because bitterns are unlikely to move throughout the season due to their territorial nature (Teal, 1989; Gilbert *et al.*, 2002; Poulin & Lefebvre, 2003b).

The calling rate per individual was modelled as a function of the variables thought likely to affect it based on the literature, giving a global model (M1, Table 3.2) with the following form:

Equation 3.2:

$$\log(CRPI_{i,j}) = \alpha+\beta_{mo}+\beta_{TD}+\beta_{yr}+\beta_{MPh}+\beta_{MV}+\beta_{cld}+\beta_{Rn}+\beta_{WS}+\beta_{WL}+\beta_{T}+\beta_{Ns}+\beta_{obs}+\beta_{int}+\beta_{rand}$$

Where α is the intercept and the β values are the effects of the variables. The fixed variables included: month (mo), time of day in relation to sunrise and sunset (TD), year (yr), moon phase (MPh), moon visibility (MV), cloud cover (cld), rainfall (Rn), wind speed (WS), water levels (WL), temperature (T), observer (obs) and background noise (Ns) (Table 3.1). β_{int} is a moon visibility interaction term (see Table 3.1), and β_{rand} represents random effects of the station and observation period ID (stn and PID).

To start I conducted preliminary analyses to decide how best to represent each variable in the global model. For example, in the case of rainfall, both a linear relationship and binary measure (did it rain or not) were tested (Table A3.1, Appendix 3). Each of these exploratory models contained the full suite of variables shown in Equation 3.2, but differed in that for each model tested, one variable in that model was substituted for an alternative form. A relationship was considered to be superior to its alternative if the Deviance Information Criteria (DIC) decreased (Burnham & Anderson, 2002; Spiegelhalter *et al.*, 2002).

Once the form of the variables was decided, backwards stepwise elimination was used to assess the predictive value of the variables. Stepwise analysis started with the removal of parameters whose posterior distributions were most centrally orientated around zero; i.e. zero was within ± 1 SD (Nakagawa & Cuthill, 2007; Zuur *et al.*, 2007). Performance of individual parameters was assessed by measuring the change in DIC values that resulted from the removal of each individual parameter (ΔDIC). A large positive ΔDIC value indicated that the parameter removed was pivotal to DIC estimation and therefore may be an important predictor for bittern calling-rates. Parameters with posterior distributions that did not incorporate zero were considered important components of the model and thus were not removed (Kéry & Schaub, 2012).

Effect sizes can be interpreted as the proportional change in number of calls produced per 15 minutes by individual bitterns (ΔCRPI) between different parameters by taking the exponential of the beta values from the models. Within a variable, ΔCRPI indicates the relative difference between the reference state and subsequent parameters provided that reference states of all other variables remain the same. For example, within the variable time of year, ΔCRPI values for the parameters October and November were estimated relative to the reference month September.

Raw continuous values for rainfall, wind speed, water levels and temperature were scaled and centred, whilst all other continuous variables were constrained to be between 0 and 1. ΔCRPI for a continuous variable gives the proportional change in CRPI (ΔCRPI) expected per unit change. For the parameter rainfall, a scaled and centred variable, a reported ΔCRPI of 0.81 would mean that CRPI would be expected to decrease by 19% (or 1-0.81) every time rainfall increases by 1 SD, which here equates to 0.04 mm rainfall (Table 3.1). For constrained variables, ΔCRPI represents the proportional change from the variables minimum to maximum level, so for moon visibility, a reported ΔCRPI of 1.55 would mean that when the moon was completely visible (maximum recorded) the CRPI is expected to be 55% (or 1-1.55) higher than when the moon is not visible (lowest value). Models were fitted in WinBUGS 1.4 using Markov chains of 300000 iterations, with the first 10000 discarded as adequate burn-in. For all models convergence was checked by visually inspecting history, density and autocorrelation plots.

3.3 Results

3.3.1 Factors influencing calling-rate

Modelling was based on 461 call-counts (293 in 2009, 168 in 2010). The number of calls recorded per 15-min ranged from zero to fifty-two, with a maximum of twelve individual birds/station detected during any one count (Figure 3.2). Four fixed factors, time of year, time of day, rainfall and moon visibility were considered important predictors of bittern calling-rates because the posterior distributions of beta values from the model were concentrated well away from zero. Similarly, based on posterior distributions of beta values, two nuisance variables (station, observation period) were considered predictors of bittern calling-rates (Figure 3.3).

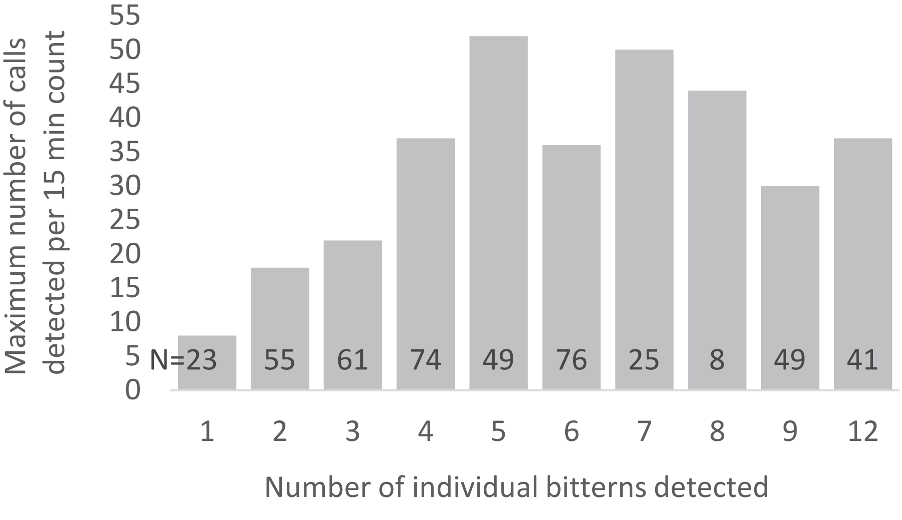

Figure 3.2: Raw calling-rates for Australasian bitterns per 15 min count conducted at Whangamarino wetland in 2009 and 2010.

Eight variables (wind speed, noise, temperature, year, cloud cover, moon phase, the interactive effect of moon visibility and moon phase, observer effect, and water levels) had little predictive value in relation to the calling-rate of Australasian bitterns as indicated by improvements to DIC values (decreases) observed following the removal of these variables (Table 3.2). The best model produced as a result of the stepwise analysis (M1i, Table 3.2, Equation 3.3) was:

Equation 3.3:

$$log(CRPI_{i,j}) = \alpha_0 + \beta_{mo} + \beta_{TD} + \beta_{Rn} + \beta_{MV} + \beta_{rand}$$

The simplified model (DIC =2774) was superior to the global model (DIC = 2783, Table 3.2) as indicated by a ΔDIC value of 9.

Table 3.2: Results of stepwise backwards elimination of variables. ΔDIC values are the change in Deviance Information Criteria (DIC) that results from the removal of each individual parameter. Removal of parameters discontinued once the posterior probability distributions of all remaining parameters no longer incorporated zero (post removal of the water level effect, Model M1i).

Model	Additional term removed		Order removed	Dbar	Dhat	pD	DIC	ΔDIC
M1	Global model	-	0	2663.09	2543.67	119.42	2782.50	-
M1a	Wind speed	WS	1	2663.22	2543.98	119.24	2782.46	0.04
M1b	Noise	Ns	2	2662.05	2543.84	118.21	2780.26	2.24
M1c	Temp	T	3	2662.30	2544.44	117.87	2780.17	2.33
M1d	Year	yr	4	2662.62	2545.01	117.62	2780.24	2.26
M1e	Cloud cover	cld	5	2660.64	2543.63	117.01	2777.66	4.84
M1f	Moon phase	MPh	6	2660.81	2543.97	116.85	2777.66	4.84
M1g	Interactive (Moon light)	int (MPh*MV)	7	2659.90	2543.67	116.23	2776.13	6.37
M1h	Observer effect	Obs	8	2660.56	2546.91	113.65	2774.21	8.29
M1i	Water levels	WL	9	2660.45	2546.92	113.53	2773.98	8.52

3.3.2 Quantifying effect sizes of predictor variables

Temporal factors: Australasian bittern calling-rates in October and November were lower than in September, as indicated by negative Beta values (Figure 3.3). The model predicted proportionately fewer calls in October, with a ΔCRPI of 0.66 (i.e. meaning that calling-rate was only 0.66 of the rate measured in the reference month September). Similarly, ΔCRPI for November was 0.29 of the September rate (Figure 3.3; Table A4.1, Appendix 4).

Model M1i predicted two diurnal apexes in calling-rate, with the first peak occurring an hour before sunrise (ΔCRPI = 1.88 in relation to 3.5 h before sunrise) and the second peak observed within the first 30 min after sunset (ΔCRPI = 0.86 in relation to 3.5 h before sunrise) (Figure 3.3, Table A4.1, Appendix 4). The calling-rate during the morning peak was therefore 2.19 times higher than the calling-rate at the evening peak (1.88/0.86 = 2.19; Figure 3.3, Table A4.1, Appendix 4).

Environmental effects: Bittern calling activity decreased with increasing rainfall, with one unit change causing a proportional ΔCRPI of 0.81 (Figure 3.3, Table A4.1, Appendix 4). Additionally, calling-rates increased by a factor of 1.55 when the moon was visible compared with when the moon was covered by cloud (Figure 3.3, Table A4.1, Appendix 4).

Nuisance variables: Some variability in bittern calling-rates was attributable to different count periods (Observation period ID) and different locations (station). As one of these effects is spatial (stations), and the other temporal (Observation period ID), the high standard deviations estimated for these parameters ($SD_{stn} = 0.32$; $SD_{PID} = 0.61$) suggest that some spatial and temporal predictors of calling-rate are still missing from the models tested.

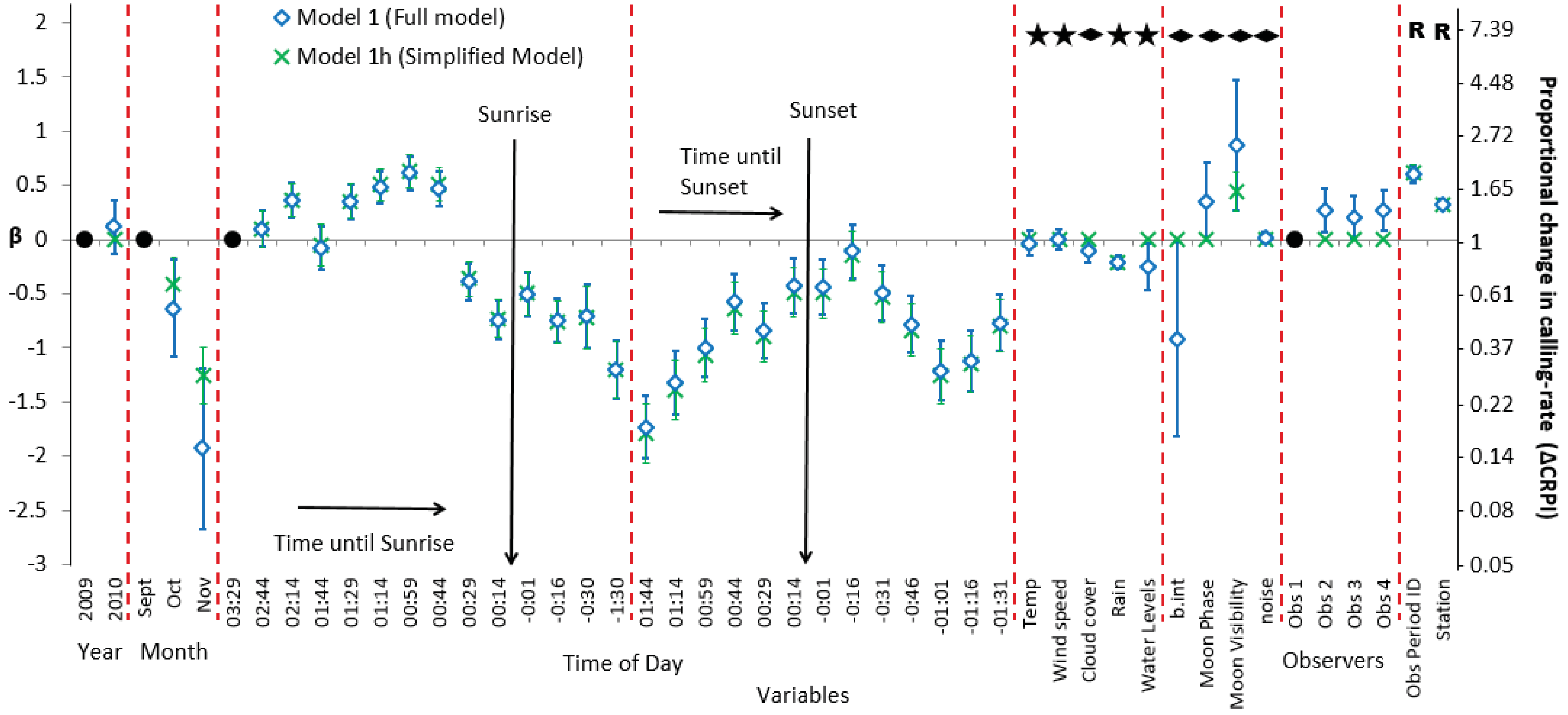

*Figure 3.3: Beta estimates from global (Model M1) and simplified (Model M1i) models. Error bars represent standard deviations of parameter estimates. Models were fitted with a log link and Poisson error term in WinBUGS 1.4. Intercept values were 1.46 (± 0.69 SD) and 1. 45 (± 0.29 SD) respectively. The parameter 'b.int' is the interactive effect moon visibility and moon phase (or MV*MPh). 'Obs Period ID' and 'Station' are the standard deviations among observation periods and stations, which were treated as random effects (**R**).Continuous dependant variables were either constrained(0 - 1, ◆) or centred and standardised (★). Black circles (●) represent reference states. The proportionate change in calling-rate attributed to each variable (ΔCRPI-shown on the right hand axis) was calculated by taking the exponential of the beta values and represents the relative difference between the reference state and subsequent parameters, provided that other reference states are held constant.*

3.4 Discussion

The need to understand factors that affect cue counts used as index measures is well publicised (Caughley, 1977; Thompson *et al.*, 1998; Williams *et al.*, 2002; Johnson, 2008b). However, most studies demonstrate the importance of predictors on calling-rates by examining variables individually (e.g. Gibbs & Melvin, 1993; Conway *et al.*, 2004). Identifying predictors in this way can be problematic in ecological studies as observed data points are not independent and are instead products of the simultaneous occurrence of multiple potential predictors. This confounds the ability to identify and quantify effects relative to one another unless large sample sizes can be obtained. As such, the true effect size of each predictor can only be determined by accounting for multiple predictors at the same time and then estimating individual effect sizes whilst all other predictors are held at their reference states. Modelling techniques are commonly used in this way for occupancy studies (e.g. MacKenzie, 2005; Gibson *et al.*, 2007) but are less prevalent when analysing call-rate as an index of abundance.

In this chapter modelling was used to compare multiple predictors of an index measure within a single model in order to develop a more reliable monitoring method. Assessing predictors within a single model allows direct comparisons across variables, providing effect size estimates that automatically account for all other predictors within the model. Identifying and accounting for all predictors in this way allows the development of index monitoring methods that have less biases and errors and therefore provide more accurate population estimates.

In the study presented here four variables were identified as important for predicting bittern calling-rates based on the stepwise procedure. These included time of year, time of day, moon visibility and rainfall. These results support studies in the northern hemisphere, where the calling of Eurasian bitterns, *B. stellaris,* in the Camargue, south of France, peak twice daily (Poulin & Lefebvre, 2003a). For this species, the first peak is reported to occur 30-60 min before sunrise, whilst the second occurs 0-30 min after sunset. Results presented here were similar with calling-rates of Australasian bitterns peaking 1 h before sunrise (1.88 times higher than 3.5 h before sunrise) and again within

30 min after sunset (0.86 times higher than 3.5 h before sunrise). Additionally, both this study and Eurasian bittern studies report higher calling-rates at dawn compared to dusk (Gilbert *et al.*, 1994; Poulin & Lefebvre, 2003b; Polak, 2006).

Similarly, rainfall was found to be an important predictor of calling-rates of Australasian bitterns, and is also associated with decreases in calling-rates for Eurasian and American bitterns. For example, Poulin and Lefebvre (2003b) reported that Eurasian bitterns call 25% less when it rains. Results here are similar, with a 19% reduction in calling of Australasian bittern predicted from light rain (0.04 mm).

Poulin and Lefebvre (2003b) also report a reduction in calling-rate of 13% when cloud cover is > 75%. In this study, cloud cover did not persist into the simplified model and therefore appears not to be an important predictor. However, moon visibility (a product of cloud cover) did persist into the simplified model. Indeed, effect sizes show that Australasian bittern calling-rates increased by 55% when the moon was fully visible compared with when the moon was completely covered by cloud. Moon visibility was not measured by Poulin and Lefebvre (2003b) and therefore was not taken into consideration in their study. It may be possible that the effect they observed was most pronounced when the moon was risen.

In this study, I included parameters for moon phase and an interactive effect of moon visibility and moon phase, both of which did not persist into the simplified model. This suggests that it is the visibility of the moon itself that is linked to increased calling-rates, rather than the time of month (moon phase) or moon light (moon phase and moon visibility).

Moon-associated effects on calling-rate are not surprising in nocturnally active species. The calling-rate of the brown skua (*Catharacta antarctica*), and whip-poor-wills (*Caprimulgus vociferous*) have both been found to increase on moon-lit nights (Mougeot & Bretagnolle, 2000; Wilson & Watts, 2006). In both of these cases, this moon effect was associated with increased foraging efficiency, which in turn was thought to cause an increase in territorial interactions with neighbouring birds and/or encourage advertising of food sources to others (Mougeot & Bretagnolle, 2000; Wilson & Watts, 2006). Similar relationships may be occurring with Australasian bitterns, as the activity-rates of several of their potential prey species have been linked to moon-related factors (e.g. the migration of adult inanga, *Galaxias maculatus*, McDowall, 1991). However, if this was the case, it would be reasonable to expect the moon visibility effect to be more pronounced at full moon, something that results here suggest is not the case (i.e. the lack of persistence of interactive effect).

The high proportional change in calling-rate that was attributed to random effects (observation period ID and station) in both the global and simplified models presented here, showed that some spatial and temporal variation remained unaccounted for during analysis. These effects are hard to separate and quantify because I was unable to fully randomise count locations and times, creating a sub-optimal sampling regime where all counts conducted after initial (randomised) start stations were in close proximity. As Australasian bittern calls are far-ranging (Teal, 1989) this may have resulted in the same calling bitterns being detected across multiple counts within each observation period. This potential pseudo-replication makes it difficult to distinguish between spatial and temporal factors in results, but should not have confounded the effect sizes of these random factors. As such, additional factors, which have not have been considered in any of these models, are likely to be affecting the calling-rate of bitterns at Whangamarino wetland but have remained unidentified. One possibility for this may be that bittern behaviours, such as space use and calling-rate, vary across individual bitterns more than expected (Chapter 6).

Model estimates, and the lack of a year effect, found in this study suggest that Australasian bittern calling-rates are predictable, and therefore could be used as a reliable index that is potentially meaningful in terms of abundance, occupancy and long-term trends (Thompson *et al.*, 1998; Lambert *et al.*, 2009; Lindenmayer *et al.*, 2012) provided call-rate is informative in terms of number of individuals (Chapter 5). Results here suggest that to monitor bittern populations reliably across time, counts should be restricted to optimum times of the day and month, preferably when there is no rain and cloud cover is low (for the moon to be visible). Standardising monitoring in this way will ensure that counts will capture the period when bittern calling-rates are the highest but also the least variable across time, therefore producing data to detect population trends over the shortest time period (Wilson & Watts, 2006).

3.5 Conclusion

This is one of the few studies to quantify the factors that influence a species calling-rate in a single model, not only allowing conservationists to predict the optimum time to monitor bitterns and allow standardisation of monitoring methods, but also, potentially, allowing effect-size estimates be used to sensibly compare call-counts from different times, allowing monitoring in sub-optimal conditions. For example, if monitoring of Australasian bitterns at a site is usually conducted in late September, but was forced to be delayed in one year until November, managers could simply adjust their count values by the ΔCRPI between those periods (0.26, Table A4.1, Appendix 4). This could have important consequences for species that inhabit inaccessible areas and are conspicuous at times that are difficult to sample (spatially and temporally cryptic). This is because once the factors affecting conspicuousness are known and quantified for that species, there is less reliance on being in the right place at the right time to maintain comparability of data. Instead managers can concentrate on getting to the right place and then adjust estimates to allow comparability with other times later. Despite this option, such *post hoc* corrections should be reserved for extreme cryptic cases as monitoring at the optimum time, if possible, should always be preferred and is recommended.

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4

Acoustic recorders as a solution to the sampling challenges of the Australasian bittern, a cryptic wetland species

The marsh crake, Porzana pusilla, another understudied cryptic wetland bird.

Credit: Adrienne Grant.

4.1 Introduction

Sampling designs dictate the strength of the inferences that can be made about a population of interest (Thompson *et al.*, 1998; Williams *et al.*, 2002; Lambert *et al.*, 2009). As a result, great care must be taken when designing monitoring programs to ensure that sampling regimes are appropriate and representative of the population and species of interest. However, adequate sampling designs can be particularly problematic with regard to cryptic species, as detections are sparse and areas of interest are often large, resulting in monitoring programs that quickly become costly in terms of time and money (Thompson, 2004). Ordinarily, when the cost of sampling an entire area of interest is too great, researchers sub-sample by defining plots or sampling units that can be considered representative of the area that has not been visited (Caughley, 1977; Thompson *et al.*, 1998; Williams *et al.*, 2002). In this way, biases that are the result of spatial variation can be limited by using random- or stratified-sampling procedures. Unfortunately, these regimes are also problematic with regard to cryptic species, as detection of these species is often logistically restricted. For example, cryptic species often inhabit inaccessible areas or can only be detected at specific times. These logistical issues prevent the application of many statistically valid sampling procedures (Chapter 1), resulting in biased inferences or small sample sizes (Chapter 1, Table 1.1).

Call-counts of male bitterns are currently the most feasible means of monitoring bittern populations (Chapter 2). However, bittern calling-rates fluctuate in response to several temporal and environmental factors, creating high variability in detection rates (Chapter 3). Standardising monitoring protocols reduces this variability but introduces logistic restrictions, creating the trade-off described above, where it becomes difficult to adequately cover an extensive sample area whilst retaining valid sampling procedures. There are three key reasons for this trade-off with bitterns:

1) The optimum time of year to detect bitterns is a short sampling window at the start of the breeding season (Chapter 3). The shorter the window the more restrictive the sampling becomes, reducing the area that can be covered.

2) The ideal time of day to sample for bitterns is one hour before sunrise or the first 30 min after sunset (Chapter 3). Unfortunately this is a time when few people are present in wetland environments. Therefore, to adequately monitor bitterns, field staff would need to work split shifts, mostly in darkness hours. This is more taxing on staff, and has greater health and safety implications compared to normal work regimes (Witmer, 2005). As such, it may be difficult to persuade staff and/or volunteer groups to conduct counts at these times (Gibbs & Melvin, 1993), particularly with respect to early morning periods. These restrictions limit our ability to sample multiple areas concurrently.

3) Sampling is limited to accessible areas. Large wetlands are time consuming and costly to access. Sampling for bitterns using statistically sound regimes is either not possible or produces small sample sizes (i.e. a small number of samples is all that can be afforded given the resources). Sampling using regimes that are more affordable, e.g. sampling accessible areas, can be biased or have insufficient power (Robbins, 1986; Gibbs & Melvin, 1997). These problems are amplified now that the optimum time to detect bitterns has been identified as one hour before sunrise – creating sampling limitations that are both spatial and temporal.

Acoustic recorders have been used to solve similar problems with other cryptic species. For example, the calls of Cory's shearwaters (*Calonectris diomedea*) are most detectable at night. This, combined with their tendencies to breed on inaccessible cliff faces on remote islands, complicates monitoring of this species (Goh, 2001). Fortunately, acoustic recorders can be used to overcome these restrictions (Goh, 2001). Similarly, recorders have been used to overcome diel and seasonal restrictions in detecting black drum (*Pogonias cromis*), and spatial restrictions associated with monitoring African forest elephants (*Loxodonta africana cyclotis*) in large remote areas (Thompson *et al.*, 2009; Locascio & Mann, 2011).

In New Zealand, the Department of Conservation has been developing two recording devices that could be deployed to monitor bitterns; one stereo option that records in MP3 format and the other is a mono option that records files in WAV format. In theory, the advantage of stereo recordings is that an observer listening to files should be able to determine the number of individuals calling, whereas only a simple index of calls per unit time can be recorded on mono recorders (Acevedo & Villanueva-Rivera, 2006). In addition, there are also several options for processing recordings. Sound files can be listened to or visually examined to look for evidence of calls on spectrograms. This provides four possible options for monitoring bitterns using recording devices: 1) Stereo recordings processed visually (STEREO-VISUAL), 2) Mono recordings processed visually (MONO-VISUAL), 3) Stereo recordings processed audibly (STEREO-AUDIBLE), and 4) Mono recordings processed audibly (MONO-AUDIBLE).

For recorders to be the preferred option (over field observers) for monitoring bitterns, then: 1) the number of calls detected by recorders would need to be comparable or better than the number detected by field observers (to facilitate replacement of observers); and 2) recorders would have to be cost effective and practical in terms of increasing wetland coverage, sampling several locations concurrently, and sampling at a specified ‘optimum’ time with greater repeatability (Chapter 3). Additionally, in some circumstances it may be advantageous to obtain estimates of the number of calling individuals. For example, number of individuals may provide a better measure of population change compared with the index measure of the number of call sequences. To a certain degree, field observers are able to distinguish between individual calling bitterns during counts, so theoretically this should be possible using stereo devices. As such there is a need to investigate whether stereo recordings processed audibly can be used to measure the number of calling individual bitterns.

This study aims to answer the following questions: 1) How well do the number of calls detected with each recording option correlate with the number of calls detected by the observer? 2) Is there a strong relationship between the number of bitterns detected through listening to stereo recordings compared with the number detected by the field observer?, and 3) Are recording devices a more cost-effective option in terms of money and effort for monitoring bitterns? As demonstrated in Chapter 1, this research is an important part of the process of developing a monitoring method, as recorders have the potential to increase sampling possibilities for bitterns (Development of a monitoring method point 5, Section 1.2, Chapter 1), and increase the feasibility of collecting larger sample sizes (Development of a monitoring method point 6, Chapter 1).

4.2 Methods

Male Australasian bitterns produce a series of unique calls or ‘booms’, here-after known as a call sequence, that are often, but not always, preceded by a series of inhalations (or pumps). Each boom within the call sequence is made up of a first element and main element as described by Gilbert *et al*. (1994) (Figure A5.1, Appendix 5). Counts of these call sequences currently presents the most feasible method of indexing male breeding bittern populations (Chapter 2).

4.2.1 Data collection

A total of 137 call-counts were conducted at Whangamarino wetland, Waikato, by field observers from September to November 2010 using the method outlined in Chapter 3. As well as having an observer in the field (OBS) during call-counts, each count was recorded using at least one of two different types of recording units (MONO and STEREO). The availability of recorders depended upon other projects, and therefore differed throughout the season. Wherever possible all three means of data collection (OBS, MONO and STEREO) were run concurrently to allow direct comparisons (Plate 4.1). However, of the 137 call-counts conducted, direct comparisons were only possible for 43 counts (OBS, MONO and STEREO), a further 80 involved an observer and mono recorder (OBS and MONO), and the last 14 involved an observer and stereo recorder (OBS and STEREO).

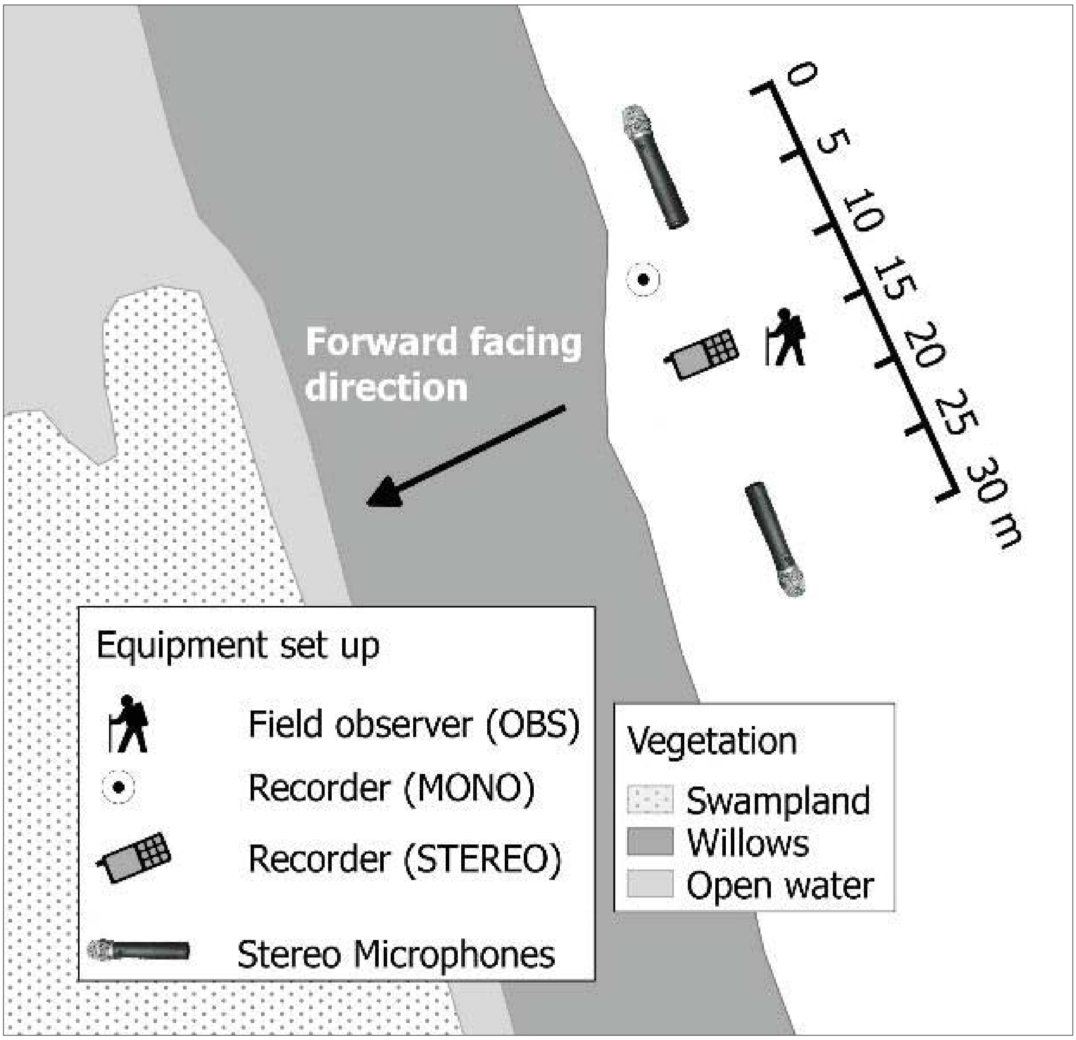

Plate 4.1: Typical placement of the two recording devices (STEREO and MONO) trialled in relation to the field observer (OBS) at Whangamarino wetland in 2010.

Each call-count lasted 15 min, after which the observer moved on to a consecutive station with the recording gear. Stations were positioned ≥ 400 m apart in accessible areas of the wetland. During counts, field observers noted all bittern call sequences and made an assessment of how many bitterns were heard calling within a count using a combination of call direction and call characteristics (call volume and number of booms in sequence). Each time a bittern was heard, observers made a judgment as to whether the call was from a new bird, or one that had been previously heard within the count. A call-sequence was considered to be a new bird if any of the following was true (Pierce, 2004):

1) The bearing of the new call is > 10° different from the bearing of any call previously heard;
2) The bearing of the new call is within 10° of another call but falls into a different volume category; and
3) The bearing of the new call is within 10° of another call, but consistently has a different number of booms within its boom sequence compared to the previous call.

Where uncertainty existed as to whether one or two birds were calling, only one bird was recorded. As a result the number of individual birds detected by observers can be considered to represent a minimum number of individuals detected.

Mono recorders, developed by the Department of Conservation (Ver. B.2; Appendix 6), were fixed at a height of 1.5m (approximately ear height, to provide the best comparability with the field observer) and secured as close to the observer as possible (within 15 m, Plate 4.1). Timers on mono units were pre-set to record automatically for the whole observation period [see Chapter 3 for definition of observation period]. Observers verbally marked the beginning and end of their counts on the recorders so that exact times on sound files could be matched correctly to field counts. Sound files could then be cut to exact count times later using the software Audacity (Version 2.0.5).

Plate 4.2: A mono recording device placed near two field observers. Credit: E.Williams.

Stereo recording units, consisting of an Olympus LS-10 recording device with two external microphones and an external 4 x D-cell power source, were placed as close to the observer as possible. Units were programmed to record at 128 kbps, at maximum recorder level, with a mic sensitivity of high and no limiter. Units were manually switched on/off by the observer at the beginning/end of each count. Each stereo microphone was positioned 15 m away from the observer at a height of 1.5 m and a bearing of 90˚ from the observer's forward facing direction (Plate 4.2).

4.2.2 Data analysis

4.2.2.1 Sound file analysis

Each sound file was analysed twice, once visually, and then again audibly by the same processor. To analyse files visually, the spectrograms of each file were examined looking for evidence of booms in Raven Pro 1.4 using the following view settings: Y-axis <900 hz, X-axis = 0-30 seconds and sharpness = 2792 (Appendix 7). Prior to visual analysis, stereo sound files were converted from their original MP3 format to WAV format so that they could be opened in Raven Pro 1.4. This was done using the website ‘online-convert.com’ (QaamGo Media GmbH, 2012) with ‘no change’ specified for the bit resolution, sampling rate and audio channel. For audible analysis, each file was listened to in real time in VLC media player with volume settings of 130% for mono recordings and 100% for stereo recordings. Audible analysis was performed using original file formats (stereo = MP3, mono = WAV). Listening volumes differed between mono and stereo devices because there was a noticeable difference between the loudness of mono and stereo recordings when they were listened to at the same volume. Sound file analysis was conducted on an ASUS A8H notebook laptop using the same set of Sennheiser HD201 headphones.

I then assessed how well the number of call sequences detected from each recorder option compared with the number of call sequences detected by the field observers within the same count. This was done using a Spearman’s correlation test, with the function ‘cor.test’ in Program R (R Development Core Team, 2010). A nonparametric test such as the Spearman’s correlation test was considered more appropriate than the more commonly used Pearson’s correlation test, because data were non-normal (approximately Poisson distributed) (Hauke & Kossowski, 2011).

Four different observers were used to collect OBS data, whilst only one person was used to process sound files. Despite this, it was not deemed necessary to investigate whether an observer effect occurred with OBS data because data from a closely related study, that used the same observers as this study, demonstrated there was no observer effect (Figure 3.3, Chapter 3).

Additionally, I made an assessment of the number of individual birds heard on stereo sound files during audible processing. To do this, an assessment was made of volume (low, med, high) and direction (left ear/right ear) for each call sequence. A call sequence was then classed as being from a new individual if the combination of volume and direction differed from calls previously recorded. Where uncertainty existed as to whether one or two birds were calling, only one bird was recorded. As a result, the number of individuals birds audibly detected on stereo recordings can also be considered to represent a minimum number of individuals detected. The ability of processors to determine the number of individual birds calling on stereo sound files was assessed using Spearman's correlation to measure the association (rho) between numbers of birds audibly detected on sound files against numbers heard by the observer in the field.

4.2.2.2 Cost benefit analysis

To determine whether recorders were more cost effective than observers I quantified monetary costs for each option (OBS, MONO-AUDIBLE, MONO-VISUAL, STEREO-AUDIBLE, STEREO-VISUAL). This cost analysis was based on a sampling regime shown to have sufficient power (> 80%) to detect a change in bittern calling-rates of ±10% at Whangamarino wetland (Appendix 8). This regime was designed to measure success (prevention of a decline in the bittern population) of a new management intervention (predator control) at Whangamarino wetland. Sampling involved conducting call-counts, lasting 15 min, at 40 stations (20 trapped, 20 untrapped), on six consecutive nights during the bittern breeding season. Costs included the initial purchase price of equipment, vehicle costs and staff wages. Wages ($25 per h) were allocated for the time travelling to and from the site, conducting call-counts, analysing sound files and setting up equipment. The price of purchasing equipment and estimates of time/effort required were based on those incurred while monitoring bitterns at Whangamarino wetland in previous years, as well as the field costs incurred during this study (using the methods outlined above).

For MONO options, I assumed the initial purchase price of each device was $300, one device was needed per station (allowing simultaneous sampling), and that each device took 2.5 min to program prior to deployment and two min to secure in place at each station. I further assumed transport time around the wetland (accessing all stations) was no more than 45 min (0.75 h) and that stations were spread evenly across the sample area. Two trips around the wetland were required, one to deploy units, and the other to retrieve them. For transport to and from the site, I assumed a driving time of 2 h return (130 km, Department of Conservation Te Rapa office to Whangamarino wetland and back) for each trip. Vehicle costs were assumed to be $ 0.77 per km (Standard mileage rate, Inland Revenue Department, 2014).

For STEREO options, I assumed initial purchase prices of $600 per device, and that one device was needed per station. Each STEREO device took approximately 3 min to program prior to deployment and 10 min to deploy. STEREO devices took longer to deploy than MONO because there were three parts to assemble and secure (two microphones and a recording unit) rather than one. Additionally microphones were placed 15 m apart, so some of this extra time involved checking distances with the tape measure. Additionally, I assumed deployment costs were accrued per sampling occasion because, unlike MONO devices, STEREO devices did not have timers, and batteries lasted < 24 h. This meant that devices needed to be serviced before each sampling occasion. Similarly I assumed transport time around the wetland, driving times to the site and vehicle costs were the same for STEREO as MONO but separate trips were required to service STEREO devices before each sampling period. Costs of sound file analysis were the same across recording devices but differed between VISUAL and AUDIBLE options. As a result, times of 0.1 and 0.25 h per sound file (i.e. 6 min per file and 15 min per sound file) were assumed for analysing VISUAL and AUDIBLE options respectively.

For OBS options, I assumed all observers attended a 0.5 h briefing prior to each sampling occasion (OBS equivalent of ‘programming time’). Separate briefings were assumed per sampling occasion because in the past the same observers were rarely available for all occasions. One observer was assumed per station (to allow simultaneous sampling). Deployment time was assumed to be minimal for observers because in prior years they were dropped off directly at count stations. This meant all they needed to do before starting was orientate themselves and organise their field sheets (< 1 min). However, unlike devices, staff preferred to be paid for their time in the wetland, so I assumed the cost of conducting counts was equal to the count duration multiplied by the number of counts and the number of sampling occasions. The time it took to move around the wetland, drive to and from the site, and vehicle costs, were assumed to be the same as for recorder options except that a complete trip was required for each sampling period. Additionally, unlike recorder options, overall travelling costs were assumed to accrue per observer because in prior years staff were paid travel time. I also assumed an extra vehicle (incurring separate vehicle costs) for every five observers used.

Additionally, to put these cost into a perspective that includes a measure of what can be achieved from each option (values), I assessed each option to see whether it could be used to do the following: 1) measure change in call-rate across time (as a surrogate for an index of abundance), 2) measure change in number of calling males as an index of abundance, 3) provide opportunities to engage local volunteers and landowners in conservation activities.

4.3 Results

4.3.1 Comparisons among devices

The number of bittern calls detected using all four recording device options were highly correlated with the number of calls detected by the field observers (spearman correlation coefficients were > 0.80). This suggested strong positive associations existed between the number of calls detected on devices and those detected by the observer, regardless of option used (Table 4.1, Figure 4.1). However, despite differences being minimal between recorder options, associations between devices and observers were slightly stronger for stereo options compared with mono options (0.89 > 0.84, Table 4.1), and slopes of visual options were closer to a 1:1 ratio compared with audible options (STEREO-VISUAL = 1.01 > STEREO-AUDIBLE = 0.96; MONO-VISUAL = 0.92 > MONO-AUDIBLE = 0.67, Table 4.1, Figure 4.1). Similarly, associations between the number of calling bitterns detected through audible analysis of stereo files was also promising, showing a strong correlation with the number of bitterns detected by the observer in the field (rho = 0.76, slope = 1.14, P = 0.00, Figure 4.2).

Table 4.1: Spearman correlation coefficients (rho) showing the association between the number of bittern calls detected using four recording options and the number of calls detected by the observer positioned in close proximity to each device.

Recorder	Analysis	rho	p	Df	N	Slope
Mono	Audible	0.84	0.00	122	124	0.67
Mono	Visual	0.85	0.00	115	117	0.92
Stereo	Audible	0.90	0.00	46	48	0.96
Stereo	Visual	0.90	0.00	54	56	1.01

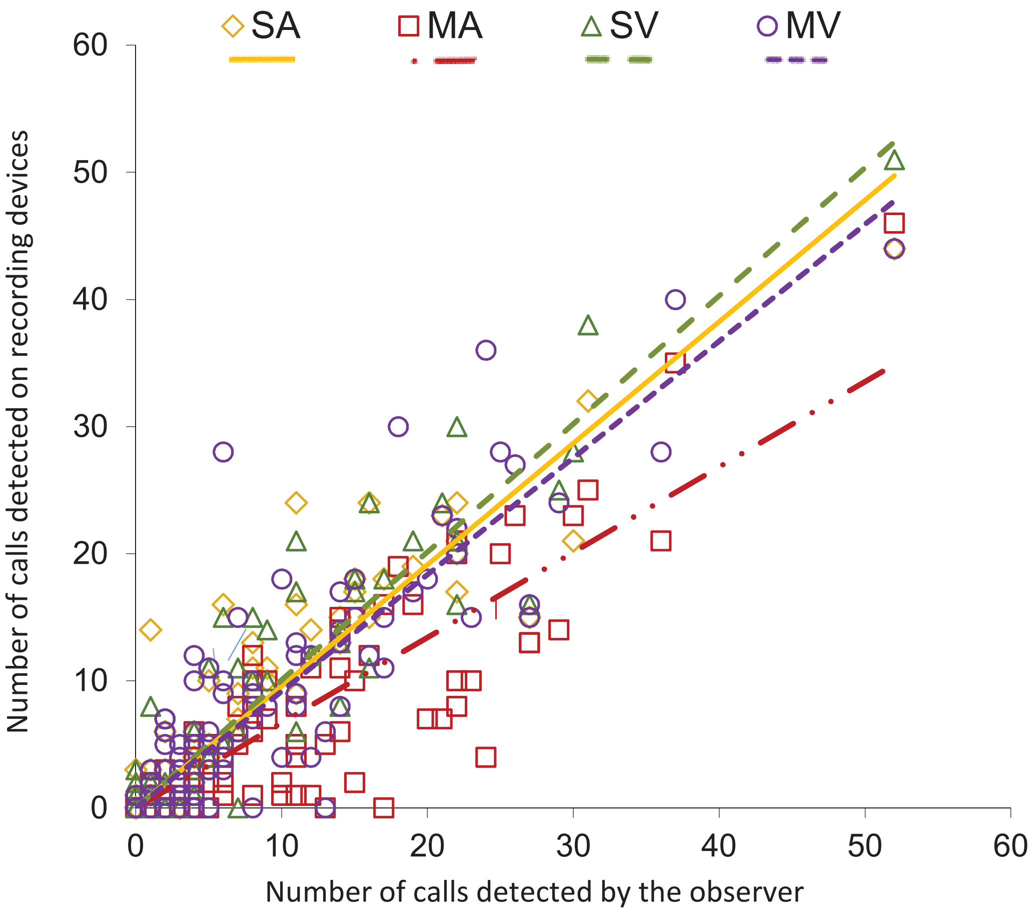

Figure 4.1: Strength of the relationship between numbers of calls detected using four recording device options and numbers detected by the field observer. Where, SV= Sound files analysed visually and produced with Stereo recorders (STEREO-VISUAL). MV= Sound files analysed visually and produced with mono recorders (MONO-VISUAL). SA= Audibly analysed sound files produced using a stereo recorder (STEREO-AUDIBLE). MA= Audibly analysed sound files produced by a mono recorder (MONO-AUDIBLE). Call-counts were conducted at Whangamarino wetland between September and November 2010. Recording devices were placed < 15 m from field observers. All intercepts have been forced through the origin.

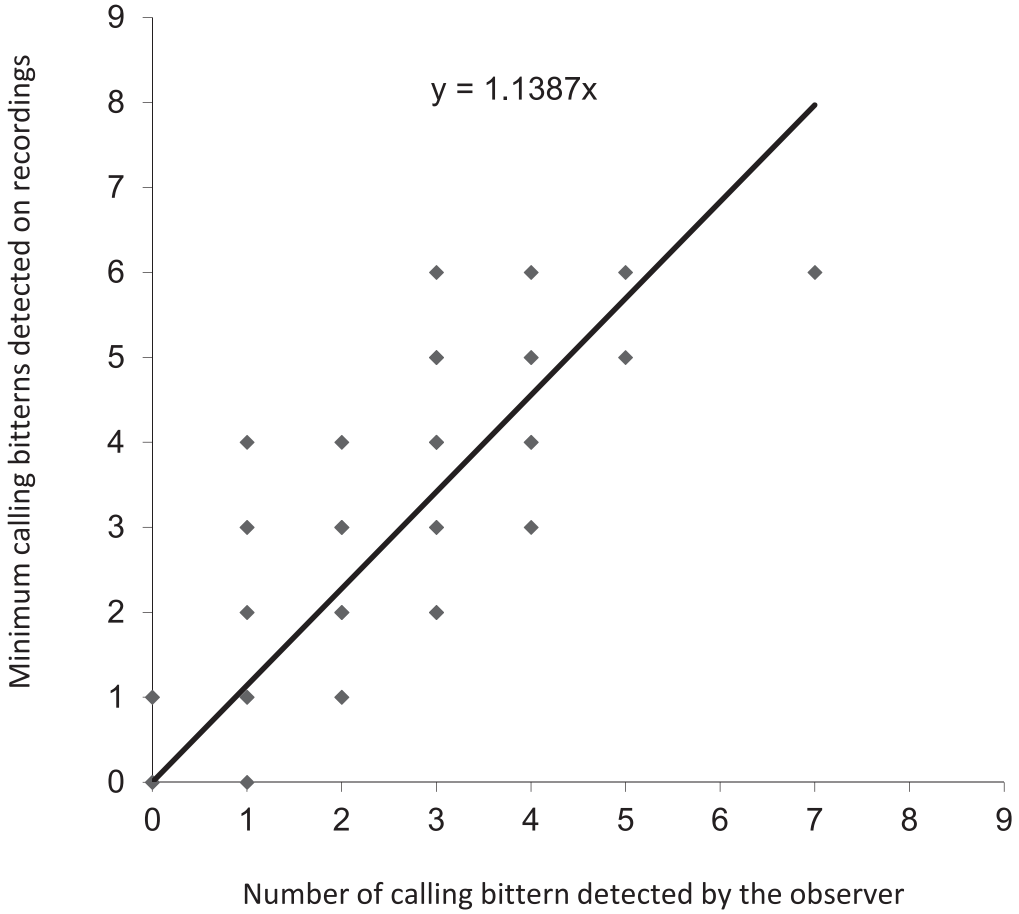

Figure 4.2: Relationship between minimum number of individual bitterns distinguished by audibly listening to stereo sound files and the number of individual bitterns distinguished by the field observer. Actual maximum bitterns is the maximum number of bitterns detected by field observers within a call-count at each station. Here the intercept has been forced through the origin. Call-counts were conducted at Whangamarino wetland between September and November 2010.

4.3.2 Cost comparisons

Cost analysis for all options showed that MONO VISUAL ($13,925) was the least expensive option followed by STEREO VISUAL ($28,113) provided two years of costs were considered (Table 4.2). Both recorder device options were cheaper than the observer option (OBS, $51,643). Regardless of device used, VISUAL options (STEREO = $ 28,113, MONO = $13,925) were cheaper than AUDIBLE options (STEREO = $29,913, MONO = $15,725). The majority of the cost associated with recording devices was in the purchase of the equipment (STEREO > 86.56% of first year costs, MONO > 88.95% of first year costs), which meant that these options were particularly cheap in subsequent years (STEREO < $2,933, MONO < $1,863). The majority of the cost with the observer option (OBS) was paying people to sit in a vehicle and vehicle related costs ($12,000 + $4,500 + $4,805 = $21,305 per year) (Table 4.2).

Table 4.2: Costs of five options considered for monitoring bitterns using a sampling regime designed to determine the success (prevention of a decline in bittern populations) of a management intervention (predator control) at Whangamarino wetland. Options being considered included combinations involving field observers (OBS), the use of recording devices (one STEREO option and a MONO option), and two sound file analysis techniques (VISUAL and AUDIBLE).

		MONO		STEREO		OBS
		VISUAL	AUDIBLE	VISUAL	AUDIBLE	
Year One	Purchase Costs	12000	12000	24000	24000	0
	Processing /counting	600	1500	600	1500	1500
	Deployment	33	33	167	167	17
	Driving to /from site	50	50	300	300	12000
	Driving around site	38	38	113	113	4500
	Programming costs	42	42	300	300	3000
	Vehicle costs	200	200	601	601	4805
TOTAL ($)		12963	13863	26080	26980	25821
Year Two	Purchase Costs	0	0	0	0	0
	Processing /counting	600	1500	600	1500	1500
	Deployment	33	33	167	167	17
	Driving to /from site	50	50	300	300	12000
	Driving around site	38	38	113	113	4500
	Programming costs	42	42	300	300	3000
	Vehicle costs	200	200	554	554	4805
TOTAL ($)		963	1863	2033	2933	25821
Cumulative Costs ($ over 2 years)		**13925**	**15725**	**28113**	**29913**	**51643**

When monitoring values were also considered as part of the cost analysis, mono options were the least diverse (could only measure call-rate) but were also the cheapest (Table 4.3). Stereo options were cost effective if the number of individual bitterns was an important measure but public participation was not valued (Table 4.3). Options using field observers were the most diverse option as observers could be used to achieve all three values. However, depending upon the circumstances, the three-fold increase in costs associated with using observers rather than mono options may not justify this diversity (Table 4.3).

Table 4.3: Performance of options in relation to three values that managers may wish to achieve while monitoring Australasian bitterns: 1. Measure of change in call-rate across time (as a surrogate for an index of abundance), 2. Measure of change in number of calling males as an index of abundance, 3. Engaging local volunteers and landowners. Values that are easily achievable are denoted with a double tick (✓✓), values that could be achieved with some work are shown with single ticks (✓) and those that are currently not achievable are shown with a cross (✗). Options being considered include combinations involving field observers (OBS), the use of recording devices (one STEREO option and a MONO option), and two sound file analysis techniques (VISUAL and AUDIBLE).

	MONO		STEREO		OBS
Values	VISUAL	AUDIBLE	VISUAL	AUDIBLE	
1. Index using call-rate	✓✓	✓✓	✓✓	✓✓	✓✓
2. Estimate of numbers	✗	✗	✗	✓	✓✓
3. Public participation	✗	✗	✗	✗	✓✓
Costs ($ over 2 yrs)	**13925**	**15725**	**28113**	**29913**	**51643**

4.4 Discussion

Several studies have shown that the quantity and quality of monitoring data can be improved by replacing field observers with recording devices (Acevedo & Villanueva-Rivera, 2006). A few authors have demonstrated the value of recording devices for solving problems in detecting cryptic species. For example, Zwart *et al.*, (2014) showed that recorders could be used to increase detection probabilities for cryptic European nightjars (*Caprimulgus europaeus*). The probability of detecting nightjars improved with recording devices because, unlike field observers, recorders can be left in the field for extended periods, allowing longer count durations for similar costs. This extension in count duration means that nightjars that vocalise in short bursts are still detected (< 10 mins per hr, Zwart *et al.*, 2014). Similarly recording devices have also been used with cryptic species to improve detection probability estimation for occupancy studies (Gorresen *et al.*, 2008). However, this is the first study to show that devices can be used to achieve a desired sampling regime for a cryptic species that would otherwise not be achievable, therefore potentially allowing a species to be monitored with sufficient power.

The comparison of the two recording devices, and two sound file processing options against field observers, made in this study, showed that any recording device option could be used instead of field observers if desired. In all four cases, data collected using recording devices was comparable with that collected by field observers (number of calls and number of individuals). Yet, costs associated with recording devices were far lower than those of the field observer (Recording devices < $30,000, Observers > $51,000). As a result, the decision of which option to use can be based upon which values are the most important given a projects monitoring objectives.

In circumstances where costs and site accessibility are not key factors limiting bittern monitoring practises then the use of observers would be the preferred option. This is because observer options are a great way to get locals involved and provide measures of both call-rate and the number of individuals calling (Table 4.3). Additionally, data is instantaneous as no sound files need to be processed. However, funds are rarely superfluous when it comes to conservation so if all three values are not required then the 73% increase in costs may not be justified (MONO VISUAL = $13,925; OBS = $51,643). The majority of the costs associated with observer options were incurred as wages and as a result of needing to make multiple trips to the wetland. As such, these cost could be reduced by using local volunteer groups e.g. ornithological society members. However, in the case of the sampling regime tested here, temporal and spatial variation in calling-rates meant 40 stations were required to achieve sufficient power to detect a change of 10% in calling-rate and it is likely that managers would be hard pushed to find and organise this many local volunteers (*pers. comm.*, Matthew Brady, Department of Conservation ranger). Additionally the time and effort required to get local volunteers safely into the heart of an inaccessible wetland for a short 15 min count would be inefficient and nonsensical. As such, observer options are best suited to areas where wetlands occur in small accessible pockets and local project buy-in is necessary or high.

If the number of individual bitterns is the desired monitoring measure but public participation is not necessary (or possible) then it would be better to take the 46% saving in costs and use the stereo audible option (STEREO AUDIBLE = $28,113; OBS = $51,643). Like observer options, deployment of stereo recorders requires multiple trips to the wetland. These costs could be avoided by increasing the battery life and data storage capacity of stereo recorders, as well as adding timers. For the sample regime tested above this would amount to a 4% decrease in costs ($1,150). Additionally there are three considerations to be made if the STEREO AUDIBLE option tested in this study is used to index number of individuals. These include:

Firstly, the strength of the relationship between numbers of calling bitterns detected using STEREO-AUDIBLE options and those detected using field observers (OBS) could vary when different processors are being used. In this study, I found that the process of deciding direction and volume used to distinguish calls from individual bitterns was subjective, requiring expertise and high concentration. Results here were based on one sound file processor (myself) but feedback from co-workers that also briefly tried the method suggested that variability in results may be high across sound file processors (Elise Verschoor, *pers. comm.,* Colin O' Donnell, *pers. comm.*). The extent of this variability would need to be determined before this method could be pursued further.

Secondly, the ability to distinguish bitterns using the criteria outlined in this study may vary with the number of bitterns calling. For example, the criteria (three volume classes and two direction classes) only provides a total of six potential outcomes, limiting the maximum number of bitterns distinguishable to six. This restriction is unlikely to have affected this study because more than six bitterns were only detected by field observers during one count. However, had the study been conducted in 2009, when as many as twelve bitterns were heard calling within similar count times (Chapter 3), results may have been different.

Thirdly, the ability to distinguish birds will be affected by the bird's location in relation to the recording device. For example, to be able differentiate between a many as six bitterns (the maximum number given the criteria above) birds would need to be distributed evenly across the 180 degree trajectory in front of the recorder (e.g. Plate 4.1). This situation is unlikely to arise at all monitoring sites, as wetlands vary in their topography. In larger wetlands, recorders are more likely to be deployed with bitterns spread around the full 360^o radius (e.g. in the middle of a wetland), and many smaller wetlands do not have uniformly linear edges meaning recorders are equally likely to be deployed on corners of the wetland ($<90^o$).

Many of these challenges could be remedied if stereo options are used in conjunction with other techniques. For example, to provide additional information to help narrow the number of comparisons required to discriminate/identify an individual using vocal individuality (Chapter 2). However, to achieve this with the stereo options trialled in this study it is important to be aware that the Olympus LS-30 recorders record in a compressed format (mp3), which contains less information about call characteristics compared with WAV-storing counterparts (such as our MONO options) (Brandes, 2008; Obrist *et al.*, 2010). If this had had any effect on call detection in this study I would have observed a lower comparability between STEREO options and observers compared with the comparability of MONO options and observers. As it happens there was little difference in this regard. This may be because mp3 compression has been designed to minimise loss of data in the range of human hearing (Rempel *et al.*, 2005; Brandes, 2008), suggesting it is suitable for use when the objectives are to replace people with the devices, as in the case of this study. However, in cases where intricate sound file analysis is required (i.e. to measure vocal individuality) options that use compressed formats will be less desirable (Brandes, 2008; Obrist *et al.*, 2010).

If call-rate is sufficient as an index of abundance alone (i.e. no additional information or public involvement is desired) then the 73% or 50% savings incurred using the mono visual option over observers and stereo audible options would be preferred (MONO VISUAL =$13,925; STEREO AUDIBLE = $28,113; OBS = $51,643). Like all index measures, calls per unit time is only useful as a measure if it correlates to abundance (Caughley, 1977). Results from other studies are mixed with this regard, with some reporting that call-rate measured using recorders correlates strongly with abundance (e.g. Payne *et al.*, 2003), and other reporting that recorders are not informative in relation to abundance (e.g. Cunningham *et al.*, 2004). In the case of Australasian bitterns it is likely that call-rate derived from recorders will be informative in terms of male bittern abundance because calling-rate is known to be predictable (Chapter 3), and the relationship between the number of calls heard and the number of calling individuals detected is strong (Chapter 5).

Additionally, the use of recording devices creates opportunities to obtain density from other techniques (e.g. combinations of call characteristics and spatial information, and array based sampling regimes; Dawson & Efford, 2009; Efford *et al.*, 2009; Mennill *et al.*, 2012; Marques *et al.*, 2013; Stevenson *et al.*, 2015). For these techniques to be useful for bitterns more information is required about the effective sampling area of recorders. Additionally, for recorders to be useful on a national scale, software that can automate the detection of calls would be useful and has already shown promise on species that have similar characteristics to bitterns in other studies (Brandes, 2008; Bardeli *et al.*, 2010; Steer, 2010; Digby, 2013; Graff, 2014).

4.5 Conclusions

In the case presented here, Australasian bitterns were a challenge to monitor due to several species-specific cryptic characteristics and a few site-specific logistic constraints. The first of these challenges was solved by showing that calling-rate is predictable in terms of time of day, time of year, and various weather conditions (Chapter 3). However, this research shows that bitterns should ideally be monitored during a short sampling window starting one and a half hours before sunrise and ending thirty min before sunrise, in September and October (Chapter 3). Monitoring using observers at this time at some sites is not feasible (e.g. at Whangamarino wetland, which is 7100 ha). For example, people cannot count all locations at sites that are large and difficult to access within tight windows and there are health and safety implications associated with having staff or volunteers out at these times. Effectively this means that the solution to our species-specific cryptic characteristic (Chapter 3) created additional temporal logistic constrains (Chapter 1). In this chapter I was able to demonstrate that recording devices not only solve our site-specific cryptic constraint, i.e. that the wetland is difficult to access, but through the use of timers and recording devices, multiple locations can now be sampled concurrently at this ‘optimum’ time, therefore, solving any additional temporal restrictions.

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5

Predicting abundance from the calling-rate of a rare cryptic bird, the Australasian bittern

A cryptic giraffe, Giraffa camelopardalis, hidden to the right, demonstrates how a species' habitat, as well as its appearance, contributes to its crypsis. Credit: Caters News Agency

5.1. Introduction

Call-count based monitoring methods, such as point counts, are used to monitor a variety of species. In general, data derived from such counts are incomplete counts that are either used as raw indices (not corrected for detectability), or as estimates (counts adjusted for detectability). Indices can be described as 'any measurable correlative of density' (Caughley, 1977) and can include direct measures, such as the number of stoats, *Mustela erminea*, trapped per night (Keedwell & Brown, 2001) or indirect measures, such as the number of mountain gazelle, *Gazella gazelle,* latrines per unit area (Wronski & Plath, 2010). Most incomplete counts represent indices that act as measures of relative abundance[1] (Rosenstock *et al.*, 2002).

In the case of indices, detection probabilities are not measured and are instead assumed to be constant (or at the very least have less variability than the desired count statistic) (Rosenstock *et al.*, 2002; Johnson, 2008). To ensure this assumption is correct, many conservation managers attempt to standardise count methodology, for example, by using the same surveyors, or identifying times and environmental conditions that may introduce variability. By ensuring these conditions remain comparable across sampling occasions, conservation managers hope to reduce variability and increase the method's ability to show trends in abundance across time.

Adjusted counts have a means of measuring detectability that is incorporated as part of the method, and therefore do not require standardisation (Diefenbach *et al.*, 2007). Adjusted counts use similar count statistics to indices but are more reliable in situations where the assumption of constant detectability may not hold, or standardisation is impractical. Examples of incomplete counts that have been corrected for detectability include distance sampling and time-of-detection methods (Farnsworth *et al.*, 2002; Pollock *et al.*, 2002; Alldredge *et al.*, 2007a; Buckland *et al.*, 2008).

In general, adjusted direct counts are preferred over index counts because detection probabilities are rarely constant, which is why past inferences made from index methods

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[1] For the purpose of this chapter 'abundance' is used as a general term to mean any count statistic relating to the number of individuals, and is therefore interchangeable with similar count statistics such as density.

have caused much controversy (Anderson, 2001; Yoccoz *et al.*, 2001; MacKenzie & Kendall, 2002; Kéry *et al.*, 2005; Alldredge *et al.*, 2007b; Johnson, 2008). However, adjusted counts may come at greater expense, are often dependant on inflexible assumptions and are not necessarily feasible for cryptic species (Thompson, 2004).

The Australasian bittern, *Botaurus poiciloptilus,* is an endangered cryptic wetland bird occurring in New Zealand, New Caledonia and Australia (BirdLife International, 2014). It presents an appropriate case study of a cryptic species because it is secretive in nature, has a camouflaged plumage, and often inhabits large, inaccessible wetlands. From the limited information available, Australasian bitterns appear to have experienced a drastic reduction in their range, which in New Zealand may coincide with a 90% reduction in their wetland habitat (Cromarty & Scott, 1996; Miskelly *et al.*, 2008; Buchanan, 2009; Ausseil *et al.*, 2011). However, little is actually known about their threats and requirements (O'Donnell, 2011). As a result, conservation managers are interested in understanding more about the causes of decline of Australasian bitterns so that key habitats can be managed to reverse these declines (Kushlan, 2007; O'Donnell, 2011).

Male Australasian bitterns produce a deep resonant booming call during the breeding season, and these calls are currently used as a means of detecting and monitoring the species. Monitoring methods currently include one call-count method and two territory-mapping methods (O'Donnell & Williams, 2015). These methods are intended to be surrogates for abundance. Detection probabilities for the two territory-mapping methods could theoretically be estimated, provided that individual booming males have high site fidelity, therefore allowing unmarked birds to be tracked between counts (Chapter 6). The third method, measuring call-rate-per-unit-time using acoustic recording devices, does not currently provide any means for estimating detection probabilities. Yet this method represents the most cost-effective and feasible way to monitor Australasian bitterns at large inaccessible wetlands such as Whangamarino wetland (Chapter 4). Therefore the ability to obtain abundance estimates from these data would be highly attractive, if it were possible.

Recently, several modelling methods have been developed that can generate detection probabilities from replicated call-count data, therefore allowing inferences regarding the probability of missing individuals that are present. Such modelling techniques are commonly used in occupancy studies (MacKenzie *et al.*, 2002; Williams *et al.*, 2002; MacKenzie & Nichols, 2004; Pellet & Schmidt, 2005; Bailey *et al.*, 2007; Rota, 2009; Moreno & Lele, 2010). Only a few are designed to estimate abundance (Royle & Nichols, 2003; Kéry *et al.*, 2005; Royle *et al.*, 2005). Yet such applications are useful. For example, Royle (2004) was able to use modelling in this way to incorporate detection probabilities into count data from the North American Breeding Bird Survey program (Robbins, 1986) – and was therefore able to get abundance estimates from a method previously thought to be limited to an index (Link & Sauer, 1998).

These modelling methods may be applicable to Australasian bitterns, especially as call-rate-per-individual has been shown to be predictable in terms of measurable variables, such as time of day, time of month, moon visibility and rainfall (Chapter 3). This predictability means that abundance could be estimated directly from observed calling-rates, provided the time of day, time of month, moon visibility and rainfall are known. Here I test this postulation with calling-rate data from two different wetlands in New Zealand (Whangamarino wetland and Lake Whatumā). At one of these sites, Whangamarino, the number of individuals calling was counted by field observers (Chapter 4) and at the second site, Lake Whatumā, the number of individuals calling was independently measured through a radio-tracking study and by plotting booming territories of all male birds on the lake using observations totalling > 150 h across > 40 days (hereafter ‘expert opinion’ method, see Chapter 6).

In this chapter, I test whether the number of calling Australasian bitterns can be estimated from calling-rate-per-unit-time. The ability to derive abundance estimates in this way is attractive as it provides a means of obtaining abundance values using recording devices. This allows monitoring of bittern populations that is more cost effective, and the use of sampling regimes in large and inaccessible areas that would otherwise be unachievable (Chapter 4).

5.2. Methods

5.2.1. Recorder deployment

Acoustic recording devices, developed by the New Zealand Department of Conservation (Ver. B.2; Appendix 6), were deployed at two different wetlands in the North Island of New Zealand (Whangamarino wetland, Figure 5.1; and Lake Whatumā, Figure 5.2). Recorders were fixed on wooden poles or trees at each site, at a height of 1.5 m, using the same method as Chapter 4.

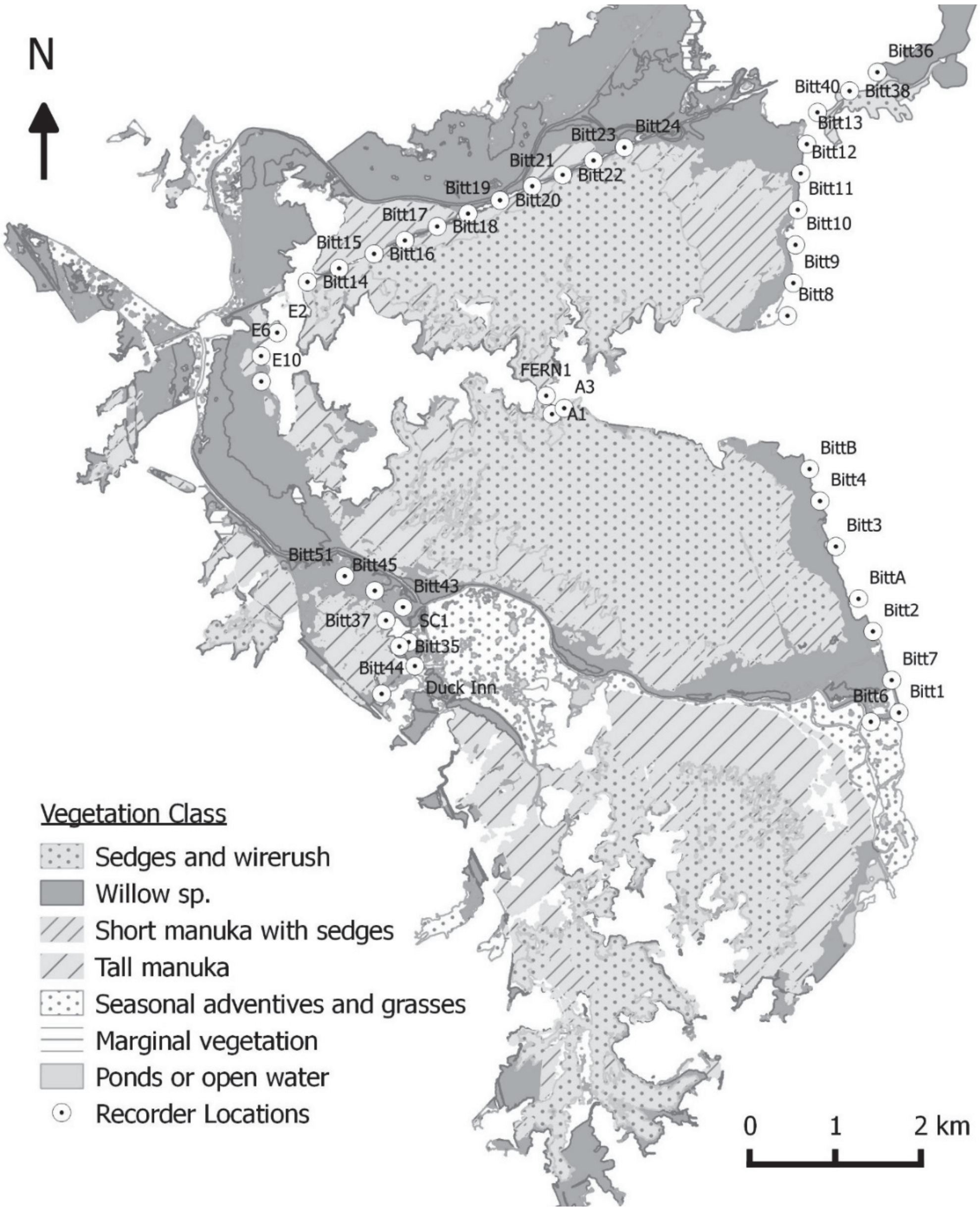

Figure 5.1: Recorders deployed at 42 point locations (stations) around Whangamarino wetland from September to November 2010.

Study sites

Whangamarino Wetland (175°07'E, 37°18'S), a 7100 ha bog/swamp complex, is 4.2 m above sea level approximately half-way between Hamilton and Auckland, New Zealand. It is the second largest wetland in the North Island of New Zealand (Ogle & Cheyne, 1981; Clarkson *et al.*, 2004; Wildlands Consultants, 2009).

At this site, recorders were deployed between September and November 2010 at 42 point locations > 400 m apart. Recorders were set to record for 15 min sound files while field observers were conducting their counts (see Chapters 3 and 4). All surveys took place during two observation periods; one from 03:00 to 08:00, and the other from 17:30 to 22:30. Two types of recording devices were used (mono and stereo).

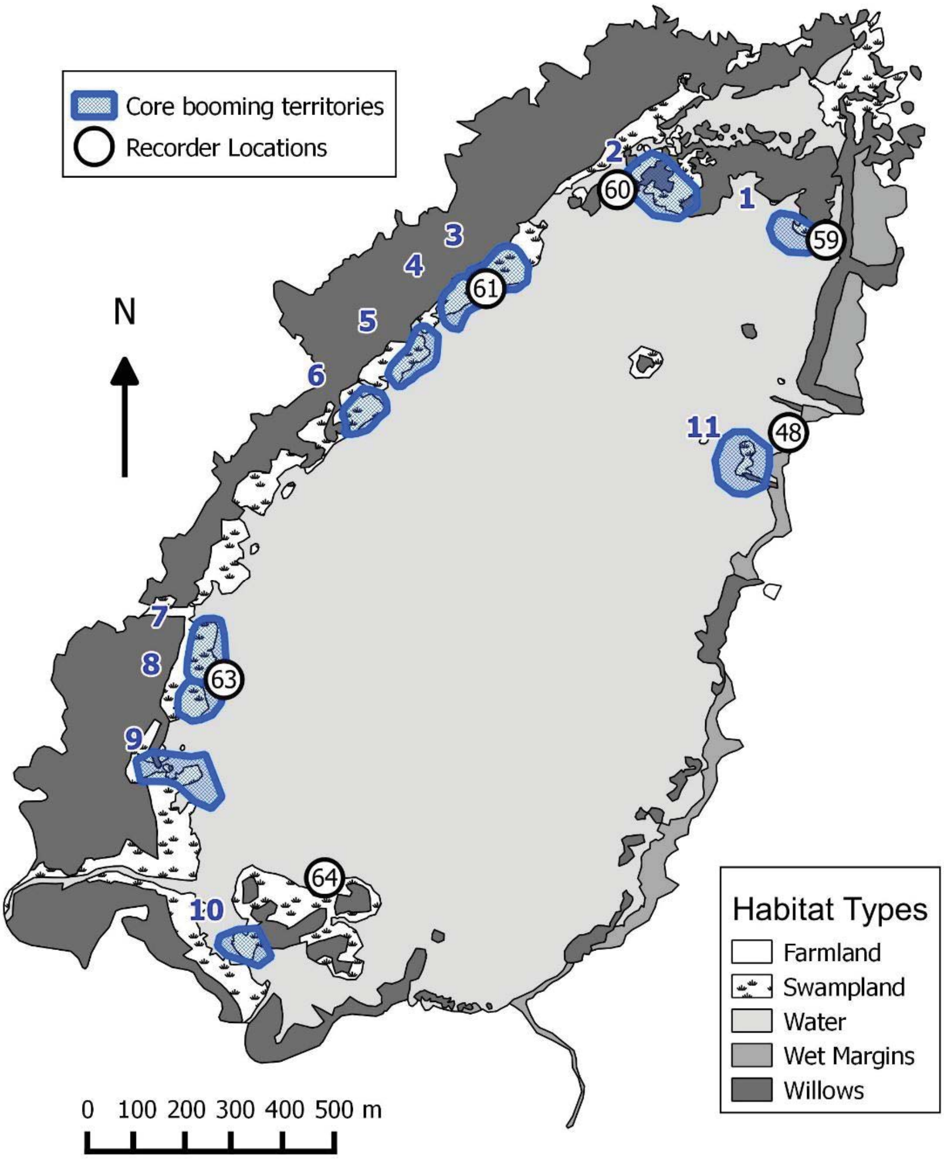

Figure 5.2: Locations of the six mono recorders deployed Lake Whatumā in 2014. Territories of male booming Australasian bitterns (blue shaded areas) were plotted using the territory-mapping method 'expert opinion' during a site fidelity study (Chapter 6). Twelve males were detected on the lake, one of which is not plotted here because his territory was not stable. Site fidelity was verified using radio-tracking data from six of the 12 male Australasian bitterns.

Lake Whatumā (40° 1'S 176° 52'E) is a small (< 250 ha) shallow lake in central Hawkes Bay. This site was chosen because six male Australasian bitterns (> 50% resident male breeding population) were captured and marked with radio-tags, for a related study (Chapter 6), in the same year that data for this study were collected. In addition, the bittern population at this site was of a reasonable size (7-10 booming males in 2011 and

2012, O'Donnell *et al.*, 2013), and breeding males were known to call (boom) from discreet, easy-to-distinguish territories. This made it possible to map the territories of all the calling (breeding) males residing on the lake, both marked and unmarked, using the method ‘expert opinion’ (Chapter 6), which provided an independent assessment of the number of calling males present.

At Whatumā, mono recorders were deployed for six days per month, between September and November 2014, at six point locations. Recorders were deployed > 400 m apart around the lake perimeter. Timers on recording units were pre-set to record for two daily observation periods: a morning period starting 1.5 h before sunrise and finishing at sunrise, and an evening period starting 30 min before sunset and finishing 1 h after sunset, producing 12 sound files per day.

5.2.2. Measuring number of calls from sound files

A total of 167 sound files were recorded at Whangamarino wetland, all lasting 15 min. This included 114 mono files and 53 stereo files. For Lake Whatumā, recorders were left out in the field continuously, meaning they generated a lot of sound files. To make this more manageable, I selected only six of the 12 observation periods available from each monthly deployment period; three morning periods and three evening periods. The observation periods with the best weather conditions were those selected (low wind and rain - determined by listening to background noise on the files). Then one 15 min sound file was randomly selected for each of these daily observation periods for processing. This gave a total of three morning sound files and three evening sound files, per recorder, per month, providing a sample size of 108 sound files. However, one recording device (064) failed in November giving 102 files (a shortfall of six).

All 167 Whangamarino soundfiles and 102 Lake Whatumā sound files were then analysed visually by one of four processors (Emma Williams, Ross Curtis, Becky Harris and Robyn Dewhurst) to look for evidence of booms or calls. Prior to the study, processors were trained using the protocols outlined in Appendix 7. Visual analysis involved examining the spectrograms of each file looking for evidence of booms in Raven Pro 1.4 using the following view settings: Y-axis <900 hz, X-axis = 0-30 seconds, and Sharpness = 2792. A ‘boom sequence’, here-after known as a call sequence, was defined as a series of booms that were made up of a first element and main element as described by Gilbert *et al*. (1994) (Figure A5.1, Appendix 5). Call sequences are often, but not always, preceded by a series of inhalations (or pumps). These were not counted in analysis.

5.2.3. Weather variables

For Whangamarino wetland, rainfall measurements (mm) were collected from a weather station at the site (175° 9'34.67"E, 37°20'56.36"S). This station took readings every two min, and returned them as averages across a 30 min period. In order to match these data with results from Australasian bittern call-count surveys, weather variables were represented as a mean value for each 5 h observation period. Moon visibility was categorised by field observers according to the amount of time the moon was covered by cloud during each survey and constrained between 0 and 1 (so that 0 = moon not visible, 0.33 = moon visible but mostly covered by cloud during the count, 0.67 = moon visible but occasionally covered by cloud during the count, 1= moon visible throughout count). Values were constrained between 0 and 1. At Lake Whatumā, some rain occurred during recorder deployment, but this was minimal. To determine whether rainfall occurred during recorded periods, sound files were visually examined for small spot-like signatures that can indicate rain. If signatures were found, files were listened to, to confirm whether or not it had rained. If rain was not heard, rainfall was assumed to have been negligible. To obtain values of moon visibility comparable with Whangamarino wetland, I classed cloud cover data from Napier airport weather station (39°28'3.47"S, 176°52'19.70"E) into four categories using the aviation classification system. So that: 0 = OVC (8 oktas), sky completely covered by clouds; 0.33 = BKN (5-7 oktas), > half the sky covered in cloud; 0.67 = FEW or SCT, sky occasionally covered by cloud; 1 = NCD, no cloud detected. These data were then corrected for whether or not the moon was risen using a 0 for not risen and a 1 for risen (allowing the parameter to be removed from the model in the instances where the moon had not risen).

5.2.4. Statistical analysis

To assess whether abundance could be estimated from calling-rate, I modified the WinBUGS 1.4 code that was previously used to model the factors affecting calling-rate-per-individual at Whangamarino wetland in Chapter 3. In the modified code, the effects estimated by the original best model (the simplified model, Equation 3.3, Chapter 3) were entered into the new model as informative prior distributions. The ‘cut’ function in WinBUGS was used to ensure that these distributions were not affected by the new analysis.

In the new analysis, the model was fitted to the new Whangamarino and Whatumā datasets to generate a new probability density function for the calling rate per individual (CRPI) for each observation period given the time of day, month, rainfall and moon visibility (using Equation 3.3). Based on these CRPI distributions, it was possible to obtain a probability distribution for the number of males present at each station based on the call counts for that station. This probability distribution is obtained by considering each new call new count (measured from the 15 minute sound files) to be sampled from the distribution (Equation 5.1).

Equation 5.1:

$$Y_{i,j} \sim \text{Poisson}(N_i \times CRPI_{\boldsymbol{i,j}})$$

Where Yi,j is the number of call sequences recorded in a 15-min call-count period, Ni is the number of males present at the station, and CRPIi,j is the expected number of calls per individual for that station during that period.

Equation 5.1 is exactly the same as Equation 3.1 which was used to model the original call-count data in Chapter 3. Except, in that analysis N_i was considered to be known and $CRPI_{\boldsymbol{i,j}}$ to be unknown. In contrast, here N_i is considered to be unknown, and is inferred from the expected values of $CRPI_{\boldsymbol{i,j}}$ calculated based on the previous analysis. Each N_i value was given a negative binomial prior (p = 0.2, r = 1), which was sufficiently wide to be considered uninformative but tight enough to avoid unrealistic numbers (95% probability that $N_i \leq 12$).

The original simplified model included two random effects (the count period, PID; and station, stn). For PID, this random effect was included in the original simplified model to account for any pseudo-replication that may have occurred as a result of not being able to fully randomise sampling (which used observers). However, in the new modified code, the inclusion of PID was not deemed necessary because samples taken from recording devices can be fully randomised. For stn, variances of the new modified model could not be estimated in the same way as the simplified model. This was because, in the original simplified model the number of calling birds was known, while in the new modified model this value is unknown. Therefore, we assumed that any variances associated with stn were the same for the new modified model as for the original simplified model (and therefore included inter-station variance as a prior, which was kept from changing using the 'cut' function).

Data used to model the factors affecting CRPI were collected by observers in the field at Whangamarino wetland in 2009 and 2010 (Chapter 3). This meant that those data were collected at the same sites as years as the new Whangamarino data analysed here (i.e. the recorders and observers were deployed together at this site; Chapter 4). No such overlap exists with the Whatumā 2014 dataset.

5.2.5. Validating model estimates

For the Whangamarino dataset, observers were present in the field while recording devices were used. I was therefore able to directly compare abundance estimates derived from the model (estimated abundance) with abundances observed by field observers (observed abundance). As explained in Chapter 3, observed abundance was taken to be the maximum number of bitterns detected within a single count across the season. Abundance estimates were considered accurate if their 95% credible intervals included the observed abundance (McCarthy, 2007). However, an estimate was considered imprecise if the difference between upper and lower values of 95% credible intervals was > observed abundance.

For Lake Whatumā, observed abundance was determined for the whole lake independently through a site fidelity study (Chapter 6). In that study, the territories of all male Australasian bitterns were mapped via their booming locations (

Figure 5.2 5.2). This provided the total observed abundance for calling male Australasian bitterns on the lake. Observed abundance was considered reasonable in terms of actual abundance because a high proportion of males on the lake were marked with radio-transmitters, and data from these birds showed that they called from discrete, easily distinguished booming locations (Chapter 6). However, because of the shape of the lake, not all calling males would necessarily have been detected on all recording devices during a survey period and the maximum distance that a recording device could detect calls is unknown (hereafter ‘effective sampling radius’). Therefore, to determine observed abundance per recording device, I calculated the number of male booming territories that fell within five different effective sampling radii for each recording device using the buffer function in QGIS (Quantum GIS Development Team, 2015). These five effective sampling radii included: 600 m, 800 m, 1 km, 1.2 km and 1.4 km. Observed abundance per recording device for each effective sampling radius was then compared against abundance estimates from the model. Abundance estimates at Lake Whatumā were considered to be accurate if their 95% credible intervals included the observed. An estimate was considered imprecise if 95% credible intervals were > observed abundance.

5.3. Results

Overall, abundance estimates were comparable with observed abundance at both sites (Figures 5.3, 5.4). The number of Australasian bitterns detected by field observers at Whangamarino wetland ranged from 1–7 per station, with abundance estimates from the model ranging from 0–10. Similarly, observed abundance for the entire Lake at Whatumā was 12 Australasian bitterns. This equated to observed abundances ranging from 3–10 Australasian bitterns per recorder location, depending upon the effective sampling radius used. These values compared well with abundance estimates from the model, which ranged from 3 to 9 depending upon recorder location (Figure 5.4).

For both datasets, accuracy of abundance estimates were high. At Whangamarino wetland, 93% of observed abundance values could be considered accurate (i.e. observed abundance fell within the 95% credible intervals of abundance estimates; Figure 5.3), while at Lake Whatumā, 83% to 100% of observed abundances were accurate depending upon the effective sampling radius used (Figure 5.4). However, precision of estimated abundance from both datasets was low. At Whangamarino, abundance estimates were imprecise for 69% of stations (i.e. the difference between upper and lower values of 95% credible intervals was > observed abundance, Figure 5.), while at Whatumā 50% to 100%

of estimates were imprecise depending upon the effective sampling radius used (Figure 5.4). Also, regardless of the effective sampling radii used, abundance estimates at Whatumā were generally lower at the northern end of the lake (stations 048, 059 and 060), and higher at the southern end of the lake (stations 063 and 064) compared to the observed abundance (Figure 5.4).

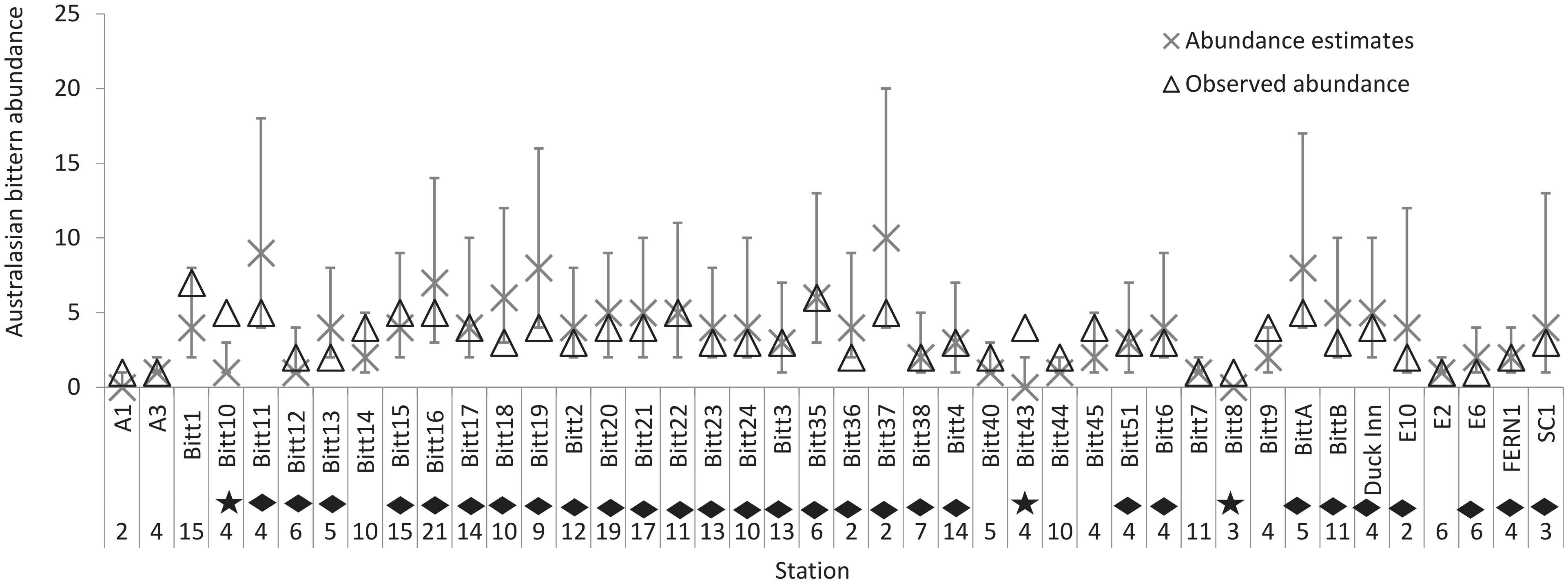

Figure 5.3: Comparisons between Australasian bittern abundances estimated from calling-rates (crosses) and observed abundances (determined by field observers –triangles) at 42 stations, at Whangamario wetland from September to November 2010. Abundance was estimated from calling-rate data based on expected call-rate-per-individual-bittern (CRPI), where the expected CRPI was calculated based on environmental and temporal variables (Chapter 3). These variables include: time of day, month, moon visibility and rainfall. Numbers beneath station names represent the number of samples used to generate estimates. Error bars show 95% credible intervals (CI) around estimates. Diamonds show estimates that were imprecise (i.e. difference between upper and lower values of 95% CI was > observed abundance). Stars show estimates that were inaccurate (observed did not fall within 95% CI).

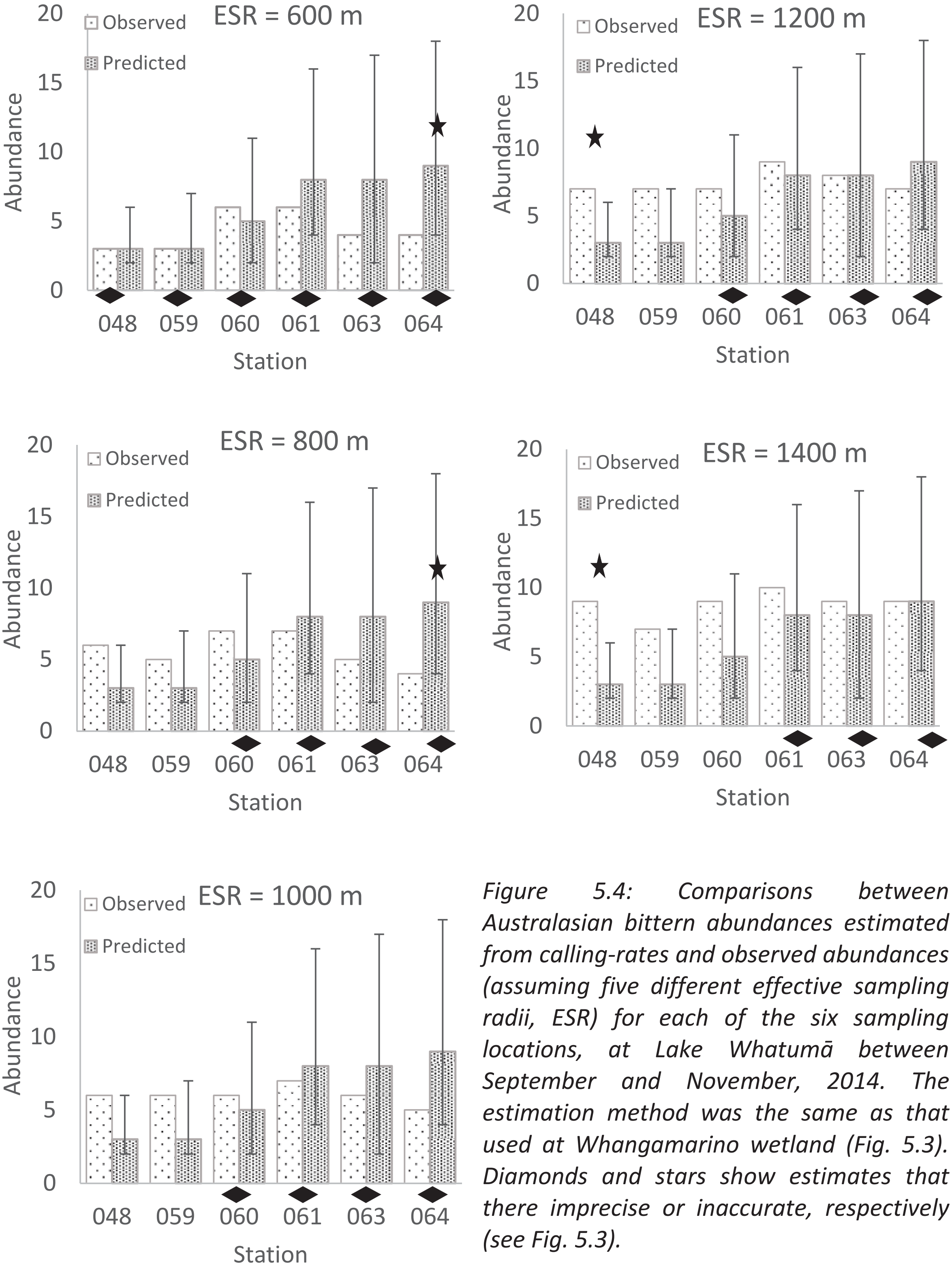

Figure 5.4: Comparisons between Australasian bittern abundances estimated from calling-rates and observed abundances (assuming five different effective sampling radii, ESR) for each of the six sampling locations, at Lake Whatumā between September and November, 2014. The estimation method was the same as that used at Whangamarino wetland (Fig. 5.3). Diamonds and stars show estimates that there imprecise or inaccurate, respectively (see Fig. 5.3).

5.4. Discussion

The importance of using incomplete counts, that have been corrected for detectability, rather than indices, is well publicised; as is the need to assess the appropriateness of assumptions underlying index methods (Farnsworth *et al.*, 2002; Thompson, 2004; Diefenbach *et al.*, 2007; Johnson, 2008). Yet few authors have examined a scenario like the one described here, where species-specific and site-specific characteristics confound the use of traditional incomplete count methods (Chapter 2).

In the study presented here, I examined whether it was possible to sensibly adjust Australasian bittern calling-rates for the number of birds not heard; therefore allowing abundance estimates from an index method. This has important implications because calls-per-unit-time, an index method, is currently the only method considered feasible for monitoring Australasian bitterns at large inaccessible wetlands (O'Donnell & Williams, 2015, Chapter 4). However, prior research suggested that the call-rate of male Australasian bitterns was predictable in terms of several environmental and temporal variables (Chapter 3). Results here suggest that these variables can be used to correct calling-rates, allowing Australasian bittern abundance to be estiamted. However, for these estimates to be informative, some improvements may need to be made to the precision of abundance estimates.

When developing a monitoring method, conservation managers need to identify and understand factors that may affect the detectability of their target species (Johnson, 2008; Etterson *et al.*, 2009). However, there are two different approaches to how this information may be used (Wellendorf *et al.*, 2004). These are: 1) to identify times and conditions when detectability is highest and the least variable, therefore allowing the method to be standardised (as an index method) or, 2) to adjust measures of calling-rate for factors known to affect detectability, therefore allowing estimates of the number of calling individuals as well as the number that were not calling (an abundance count adjusted for detectability). The choice of which approach is the most appropriate will depend upon the objectives of monitoring, the assumptions of the data used to build the original model, and the model selection process used in Chapter 3.

5.4.1. Objectives of monitoring

Index methods are useful for showing population trends across long timeframes, but are less useful for identifying causes of these trends or enabling proactive management interventions (Hutto & Young, 2002). This is because these methods rely upon maintaining constant detection probabilities between sampling occasions (Rosenstock *et al.*, 2002; Johnson, 2008) - something that is difficult to achieve, particularly with species that are spatially and temporally cryptic (Chapter 1). For these species, sampling is logistically restricted and conservation managers have less flexibility about when and where monitoring can take place (Chapter 1). Usually, under these circumstances, monitoring is forced to occur outside of the standardised conditions. This introduces biases into the data and reduces the method's ability to meet its objectives (Thompson, 2002).

The high accuracy of abundance predictions found in this study suggest that these sampling problems are solvable for Australasian bitterns because call-counts can be adjusted for factors known to affect calling-rate (the second approach). This means that differences in calling-rates (that are not attributable to population changes) are known and can be measured between sampled times (Chapter 3). The ability to adjust for these differences adds flexibility to the times and conditions that monitoring can occur, potentially increasing sampling possibilities.

Similarly, raw index methods do not provide any information about the number of Australasian bitterns not detected, meaning population numbers will always be underestimated (MacKenzie *et al.*, 2005). Adjusting counts for the number of individuals not detected should provide more accurate population estimates (MacKenzie & Kendall, 2002), meaning management practises are better informed. In theory, this should enable a method to meet its objectives more easily (i.e. detect a trend). However, the lack of precision observed with abundance estimates in this study suggests that adjusted counts may have less power to meet method objectives compared with raw (unadjusted) index counts (*sensu* Murphy, 2014).

Such a reduction in power, as a result of lack of precision, would be a concern. Endangered populations require monitoring methods that are informative within short spaces of time as such populations are less resilient to population changes, and require prompt changes in management practises (Forcada, 2000; Clarke *et al.*, 2003). Therefore, more work is required to determine how a method's power to meet its objectives is affected when counts are adjusted.

However, it may also be possible to improve the precision of abundance predictions. For example, the best model from Chapter 3, which was then used in this study to adjust counts, contained a high number of parameters, something that is associated with reduced precision (Burnham & Anderson, 2002). Yet, the majority of these parameters relate to one variable - time of day (TD). Currently this variable is represented categorically using 27 temporal parameters, each 15-mins in duration (Chapter 3). Theoretically, it should be possible to represent relationships like this one using fewer parameters; therefore, potentially improving precision, and the method's power (Burnham & Anderson, 2002). Another possibility is that the model selection criteria used to explain calling-rate-per-individual (in this case DIC) was not appropriate to predict abundance. Indeed, Ward (2008) has shown that the performance of model selection criterion can vary with question complexity and depending upon whether explanatory or predictive power is desired.

Aside from the method's ability to meet its objectives, it would be preferable to communicate population trends in terms of abundance, rather than calling-rate. This is because abundance is more meaningful and understandable compared with changes in calling-rate. The ability to communicate population trends to audiences from varying backgrounds is essential, especially for obtaining land-access permissions and funding (Rodger & Moore, 2004); as do any conservation measures that rely on changes to mainstream practises. Yet, buy-in and participation from the public is often the hardest thing to secure (Hutto & Young, 2002).

5.4.2. Assumptions of the data used to build the underlying model

The ability to predict abundance by adjusting counts is dependent upon the predictive abilities of the underlying model. In the case presented here, data used to identify factors affecting of calling-rates were subject to two assumptions (Chapter 3): 1) that all males present were detected at least once by observers, and 2) that males at Whangamarino wetland stayed within the same sampling area during the breeding season. These assumptions are considered reasonable because observers detect a high proportion of the total birds within single count periods (Chapter 6; O'Donnell *et al.*, 2013) and individual Australasian bitterns have high site fidelity during the breeding season (Chapter 6). However, at least two males present at Lake Whatumā emigrated during the breeding season in 2014 (Chapter 6), proving that not all calling birds remain within the same sampling areas throughout the season.

5.4.3. Model selection process

Model selection identifies the model that is the ‘closest approximation to the truth’ by ranking competing models (candidate models) (Burnham & Anderson, 2002). However, this means that any model ranked as the ‘best’ model is only superior to the other models ranked in the candidate set (Burnham & Anderson, 2002). This means that quality of any abundance estimates derived using the model presented here, would be dependent upon the predictive ability of the simplified model from Chapter 3, and the global model that it was ranked against.

This global model contained a suite of variables considered relevant based on recent literature and consultation with other bittern experts. As such, it was designed as a comprehensive *a priori* representation of what factors might affect Australasian bittern calling-rates. However, little information was available that explained why some of these factors may affect Australasian bittern calling-rates. This made it difficult to know whether all important factors had been considered, and whether these factors were being represented effectively by the variables used (e.g. the form of the relationship was appropriate). As a result, it is possible that some important factors were not included in this global model, and therefore were not identified as important. This could explain why some spatial and temporal variability remained unexplained in our simplified model, as indicated by the persistence of the two random effects (Figure 3.2, Chapter 3, Kéry & Schaub, 2012).

Similarly, it is possible that some of the variables identified as important represent indirect rather than direct relationships. For example, call function of male Australasian bitterns is probably associated with mate attraction and territory defence (Teal, 1989). This suggests that the strongest factors affecting Australasian bittern calling-rates may be breeding status and stage. These factors could not be directly measured, and therefore are not included as priors in the global model (Chapter 3). However, factors like month and water levels are expected to be correlated with breeding stage. The fitted model could therefore be misleading in any circumstance where the timing of breeding is different from the timing that occurred during this study.

Despite this, many factors thought to be associated with breeding status and stage, such as time of year (Teal, 1989; O'Donnell, 2011), were included in the model and persisted into the final simplified model (Chapter 3). Therefore, it is possible that the effects attributed to these variables were actually associated with breeding success and stage. If this is the case, abundance predictions from the simplified model could be misleading in any circumstance where the relationship between these variables and breeding status/stage differs from that experienced during this study.

The concerns outlined above highlight why models should be tested on independent datasets (Burnham & Anderson, 2002). The Whangamarino dataset used in this study was different from the dataset used originally to identify factors that affect calling-rate (see Chapter 3). However, this dataset is not a true test of model suitability because recorders and observers were present in the field during the same time periods, meaning that the same bitterns were being sampled across both datasets, and sometimes under similar circumstances (Chapter 3, Chapter 4). Despite this, abundance predictions at Lake Whatumā were independent (different site, different year) - making the high accuracy of abundance predictions observed at this site particularly encouraging.

In conclusion, indices are limited in their usefulness because they require long-term monitoring that is ill-afforded in the case of endangered species. The approach used here shows that it is possible to get abundance estimates for a species that would normally be monitored using an index method. This is particularly advantageous if abundance is more understandable to target audiences, or logistical challenges limit monitoring opportunities (temporal and spatial crypsis). However, feasibility and usefulness of this approach depends upon the predictive abilities of the underlying model and power to detect population changes. More work is required to determine whether the approach used in this chapter is robust to any changes in predictive ability and power that may occur.

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6

Measuring site fidelity to validate assumptions of methods used to monitor Australasian bitterns

A leaf mimic katydid, genus unk (centre of photo). *Credit: www.somepets.com.*

6.1. Introduction

Monitoring threatened wildlife populations is important to allow for correct prioritisation of management interventions and resources, as well as in determining the effectiveness of management practises (Clarke *et al.*, 2003; MacKenzie & Nichols, 2004). This can only be achieved through the use of monitoring methods that are reliable in terms of their objectives. Unfortunately, some indexing methods are too biased or imprecise to meet their objectives (see examples in Clarke *et al.*, 2003). To ensure the appropriateness of a method, it is important to evaluate the underlying assumptions in relation to behavioural traits of the targeted species (Clarke *et al.*, 2003). This can be problematic in the case of cryptic species as these species are data-deficient, meaning behavioural traits are not well understood.

This need for behavioural information, as part of monitoring-method development, is illustrated by the Australasian bittern, *Botaurus poiciloptilus*, a cryptic wetland bird found in New Caledonia, Australia and New Zealand. Classified as Endangered by the International Union for Conservation of Nature (BirdLife International, 2014), Australasian bittern populations have experienced drastic reductions in their range (Miskelly *et al.*, 2008; Buchanan, 2009). Population guesses for Australia and New Zealand are <1000 birds per country, and recent reports from New Caledonia suggest the species is now extirpated (Heather & Robertson, 1996; Garnett *et al*. 2011 in: Department of the Environment, 2015). Despite these population guesses, little is known about the species' ecology (Marchant & Higgins, 1990; Heather & Robertson, 1996; O'Donnell, 2011). There is a need to develop monitoring methods for this species that can confirm the true status, trends and threats of populations, and help reverse declines (Kushlan, 2007; O'Donnell, 2011).

Monitoring bitterns is challenging because they have all four of the categories associated with species that are difficult to detect (visual, behavioural, temporal and spatial crypsis, Chapter 1). Dense vegetation and secretive behaviour prevents the use of any methods that rely on visual counts (territory-mapping using sightings, and traditional mark-recapture). As a result, monitoring methods that depend upon non-visual cues are required. The booming call produced by males during the breeding season is currently the most feasible cue available for detecting Australasian bitterns (Chapter 2). This is because calls are distinct and far reaching. In particular, two territory-mapping methods have been identified as feasible for monitoring Australasian bitterns. These include: acoustic triangulation and close approaches (Table 2.5, Chapter 2).

However, both of these methods rely on the assumption that male bitterns have distinct territories and high site fidelity during the breeding season; something that has not been tested for any bittern species. Here I test this assumption on a population of bitterns at Lake Whatumā, where approximately 50% of calling male bitterns were radio-tagged. I also compare population estimates produced by naïve observers, using both territory-mapping methods, with the number of calling bitterns detected by expert observers that surveyed bittern territories for > 150 h (hereafter, the ‘expert opinion’ method).

6.2. Methods

6.2.1. Study area

Lake Whatumā (40^{o} 1’S 176^{o} 52’E) is a small (< 250 ha) shallow lake (< 2 m depth) located in central Hawkes Bay (Figure 6.1). Lake Whatumā was chosen, rather than the larger site, (Whangamarino wetland (7100 ha), used in Chapters 3 and 4) because prior knowledge of the bittern population suggested there was a good chance of catching and marking a high proportion of the male breeding population (O'Donnell *et al.*, 2013). Also, the bittern population was of a reasonable size (7-10 booming males in 2011 and 2012, O'Donnell *et al.*, 2013) located within a small area and isolated from other bittern populations. These criteria enabled both territory-mapping methods to be run consecutively and meant that the territories of all individual bitterns, and areas of bittern habitat, could be accessed by the expert observers within a short sampling window (e.g. ca. 3 h).

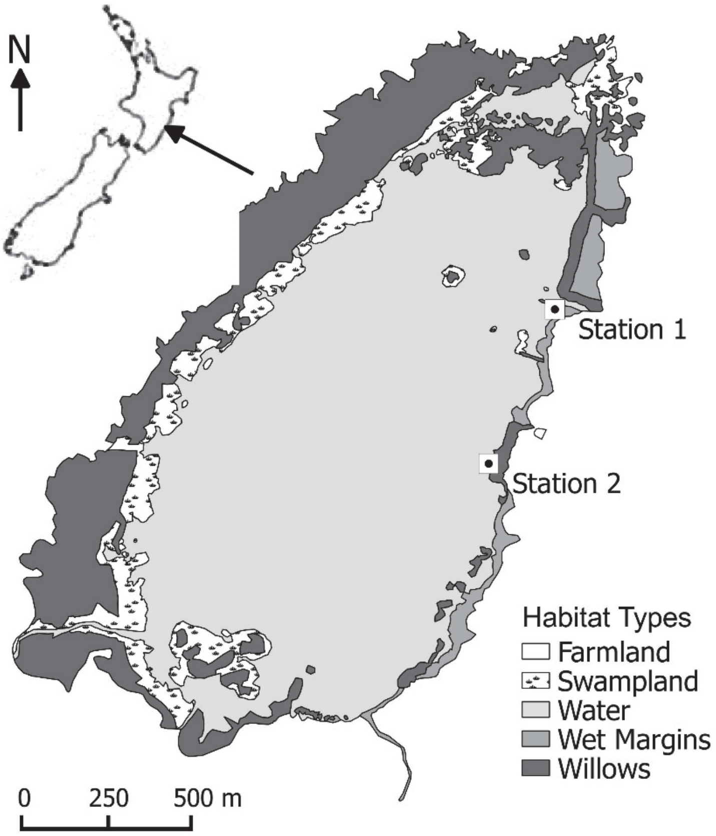

Figure 6.1: Lake Whatumā located in central Hawkes Bay, New Zealand. Station 1 and 2 are locations used to listen for bitterns as part of the acoustic triangulation method (see text).

6.2.2. Mapping territories using naïve observers (two territory-mapping methods)

From September to November 2014, the number of booming males on the lake was estimated monthly by observers that had little or no prior knowledge of the location or numbers of bitterns present on the lake (naïve observers). Prior to each count, observers were provided with basic training on how to monitor bitterns using two territory-mapping methods: acoustic triangulation and close approaches (O'Donnell & Williams, 2015).

Acoustic Triangulation: Observers noted all calls heard during a 1 h period from two accessible locations ca. 500 m apart along the lake shore (Stations 1 and 2, Figure 6.1). Counts were conducted during the times of day identified as optimum, i.e. 1 h before sunrise or within the first 30 min of sunset (Chapter 3). Prior to counts, naïve observers were provided with basic compass training and taught how to decide if a call heard was likely to be from a new calling individual bittern or one that had previously called. This decision was based on the bearing of the call, call characteristics (such as the number of booms within boom sequences, times between booms and boom sequences) and call volume (a substitute for distance to bird).

Close Approaches: Observers slowly circumnavigated the lake using a kayak, noting the presence of any booming birds as they passed around the lake margin. Using this method, it was possible to approach booming birds from more than one direction or even circle a booming bird to improve confidence in estimates of its location. When confident of the location of a booming bird, and that the booms were not produced by more than one bird at that location, observers noted the location on a map or recorded the coordinates using a Garmin GPSmap 60CSx. They then moved on to where the next bird was booming along the lake shore. This technique relied upon spending as long as the observer thinks is required to be confident about the locations of all booming birds on the lake. For example, counts at Lake Whatumā conducted by O'Donnell *et al*. (2013) took 5 h using one observer and 3.5 h using three observers. Multiple observers conferred during and after counts to confirm bittern locations. Counts were conducted between 14:00 and sunset.

After the monitoring period had finished, regardless of which method was used, naïve observers reconvened to discuss their individual findings and jointly decided upon the overall number of booming bitterns detected on the lake. During these discussions one expert observer (EW) remained present to provide advice and answer direct questions relating to the interpretation of the bittern protocols, but would not comment on how many bitterns were present on the lake, where bitterns were located or whether or not observers were correct in their conclusions.

6.2.3. Mapping territories using expert observers (Expert opinion method)

Marking individual bitterns[1]: Six male bitterns were captured at Lake Whatumā using cage traps from August to November 2014 (Huschle *et al.*, 2002, Table A7.1, Appendix 7) as part of Department of Conservation (DOC) Science Investigation 4231. Once captured, each bittern was fitted with a numbered metal butt-end band (size M; New Zealand banding office) and a 2-stage Sirtrack® transmitter weighing < 19 g (< 1% of body weight). Transmitters were attached to each bird using a back-mounted harness design made of braided nylon cord with a weak link (Karl & Clout, 1987). Each transmitter produced a signal on a unique frequency allowing marked bitterns to be identified and located even while the bird was hidden in the dense vegetation.

Measuring site fidelity of marked and unmarked bitterns: Four sxperienced observers (myself, Colin O'Donnell, John Cheyne, and Gail Cheyne) located marked bitterns on the lake every third day (on average) by following transmitter signals using TR-4 or TR-2 receivers with three-element Yagi antennae. Once the observers were confident they were within 50 m of the marked bird they captured the co-ordinates of their location using a Garmin GPSmap 60CSx or plotted the bird's location directly on a map. Observers also noted whether or not the bittern was booming. During this process the same observer noted locations and times of any other (unmarked) males heard booming on the lake to the same locational accuracy. Observers remained on the lake until they were confident they had accounted for the presence (or absence) of all male bitterns within their targeted area (ca. 3 h each time, > 150 h total across > 40 days). The length of time that they waited to confirm the presence/absence of unmarked birds, via their booms, was determined from experience listening to how frequently marked bitterns boomed. Observers also recorded the GPS locations of any birds heard booming while they were on the lake doing other tasks (to the same accuracy).

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[1] Capture techniques, banding permits and ethics for harness tags were approved by the DOC Animal Ethics Committee under its Standard Operating Procedure (File DOCDM-708212) for approved radio-tracking techniques for Australasian bitterns (File DOCDM 791275).

6.2.4. Data analysis

To determine site fidelity of marked bitterns, I calculated the area for each marked bittern that had a 95% probability of containing the bird - also known as the bird's Utilisation Distribution (UD, Van Winkle, 1975). This was done with Kernel Density Analysis using Silverman's rule in QGIS 2.4.0-Chugiak with the plugin 'Animove' (Boccacci *et al.*, 2014).

To check whether UD size was temporally correlated, I calculated the distance between each bird's location and the centre of that bird's 95% UD. These distances were then classed into two time periods, one representing the recommended optimum time of year to monitor bitterns (3 September – 14 November, Chapter 3) and the other representing later data (14 November – 3 December).

To establish whether individual bitterns boom from discrete territories, I compared the UDs and core booming locations of marked bitterns with those of unmarked birds. To do this, booming records of both marked and unmarked bitterns, collected across the season by the expert observers, were classed into individual core booming territories. Booming at Lake Whatumā appears to occur from separate distinguishable locations (O'Donnell *et al.*, 2013). For example in discrete raupō (*Typha orientalis*) patches that are < 100 m in diameter, or separate ends of larger raupō patches. A boom was therefore considered to belong to an individual's core booming territory if it was produced from a discrete location where booms had consistently been heard previously. Any booms that occurred outside of these areas were only classed into a new core booming territory if booming became regular at that location (> 10 booms heard), or if the bird was unmarked and all other unmarked males had been accounted for (heard booming) within the same sampling window.

How well-defined and discrete core booming territories were could be determined by examining: 1) whether or not any marked bitterns boomed within the core territory, or UD, of other bitterns, 2) what proportion of each marked bird's UD was being used for booming, and 3) whether core territories and the UDs of marked bitterns overlapped with those of other bitterns.

6.3. Results

6.3.1. Site fidelity of marked bitterns

Between 12 and 79 locations were recorded for the six marked bitterns between 3 September and 3 December 2014, with the final number of fixes depending upon the date when birds were marked. In general, bitterns at Lake Whatumā had high site fidelity during the breeding season, but there was high variability between the areas of 95% UDs (Utilisation Distributions) among the marked bitterns (12.46 ha, ± 10.16 SD, Table 6.1). The UDs of three marked birds were discrete (non-overlapping) and localised (bitterns named Barry White, Prince Tui Teka and Tama Tomoana, Figure 6.2). A fourth marked bittern (Bing Crosby) had a discrete localised UD but left the lake permanently mid-way through the breeding season. The UDs of the fifth and sixth marked birds (Elvis Presley and Howard Morrison) were not discrete (overlap area = 16.73 ha, 65% and 76% of UDs respectively, Figure 6.2). Some temporal correlation was apparent for one marked bird, Barry White, who was found more regularly at greater distances from the centroid of his territory after the optimum time of year for monitoring bitterns compared with during the optimum period (Figure 6.3). No change in distance from centroid was found for the other five radio-tagged bitterns. However, two of these birds (Elvis Presley and Prince Tui Teka) were marked later in the season and therefore had few observations within the optimum monitoring period.

Table 6.1. Utilisation distribution and core booming territory descriptors for six male Australasian bitterns marked with radio-tags at Lake Whatumā from August to November 2014. Core booming territories were defined using the method 'expert opinion'. Areas of 95% Utilisation distributions (UD) were calculated using Kernel Density Analysis with Silverman's rule in QGIS 2.4.0-Chugiak with the plugin 'Animove' (Boccacci et al., 2014). n = the number of booming locations obtained per bird.

Marked Bittern	Proportion of booms within core booming territory	*n*	Core booming territory (ha)	Area of 95% UD (ha)	Core booming territory as a proportion of 95% UD
Bing Crosby	0.67	6	0.65	8.56	0.08
Prince Tui Teka	0.67	6	0.60	1.83	0.33
Tama Tomoana Howard	1.00	19	0.93	1.71	0.54
Morrison	0.88	8	1.14	22.08	0.05
Elvis Presley	0.67	3	0.58	25.66	0.02
Barry White	0.81	37	1.16	14.91	0.08

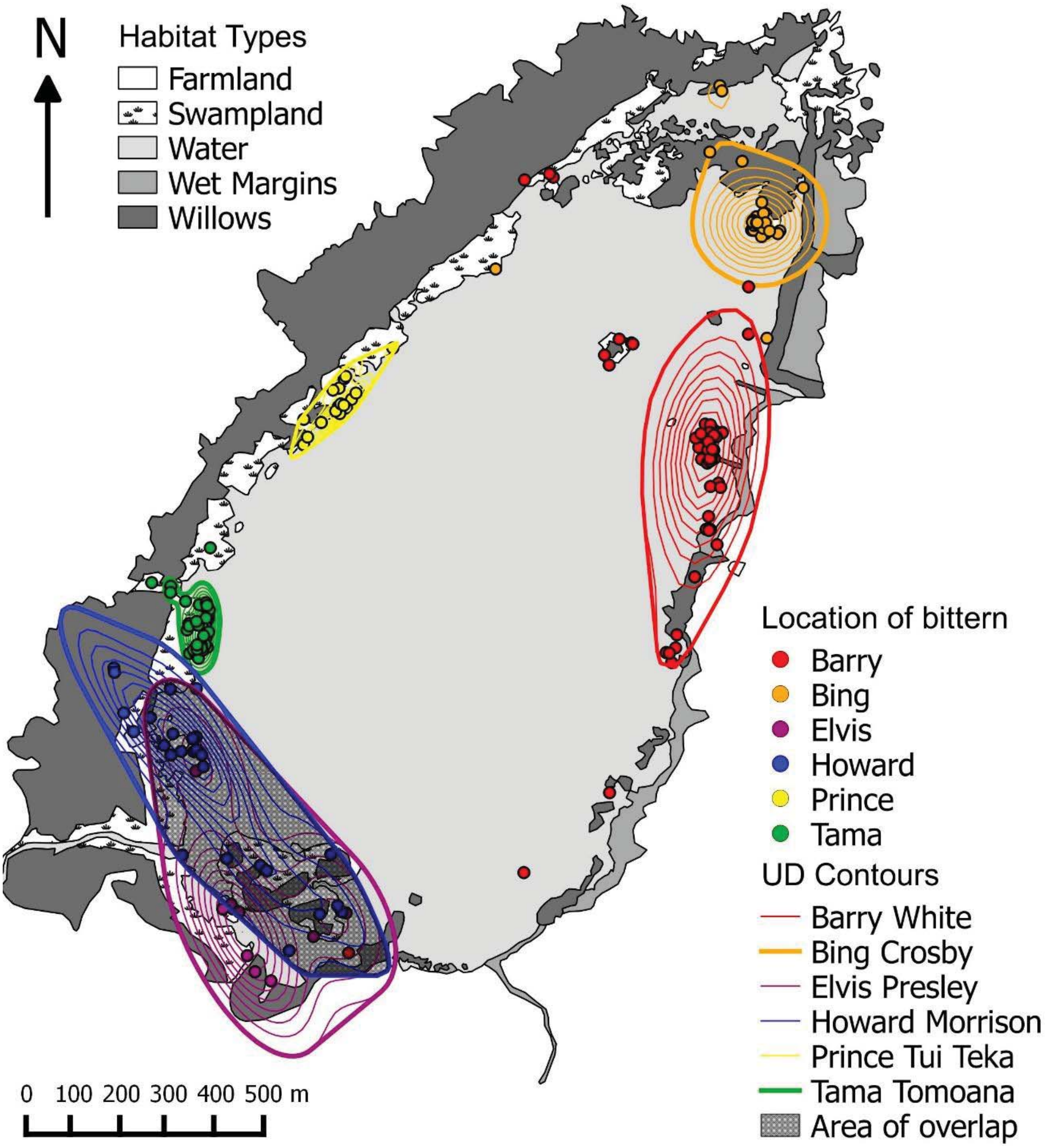

Figure 6.2: Utilisation distributions of six marked Australasian bitterns at Lake Whatumā between September and December 2014. Birds were located and identified by following signals emitted by their attached radio-tags. Locations include booming and non-booming records. Contours represent Utilisation Distributions at increments of 10 from 5% to 95%.

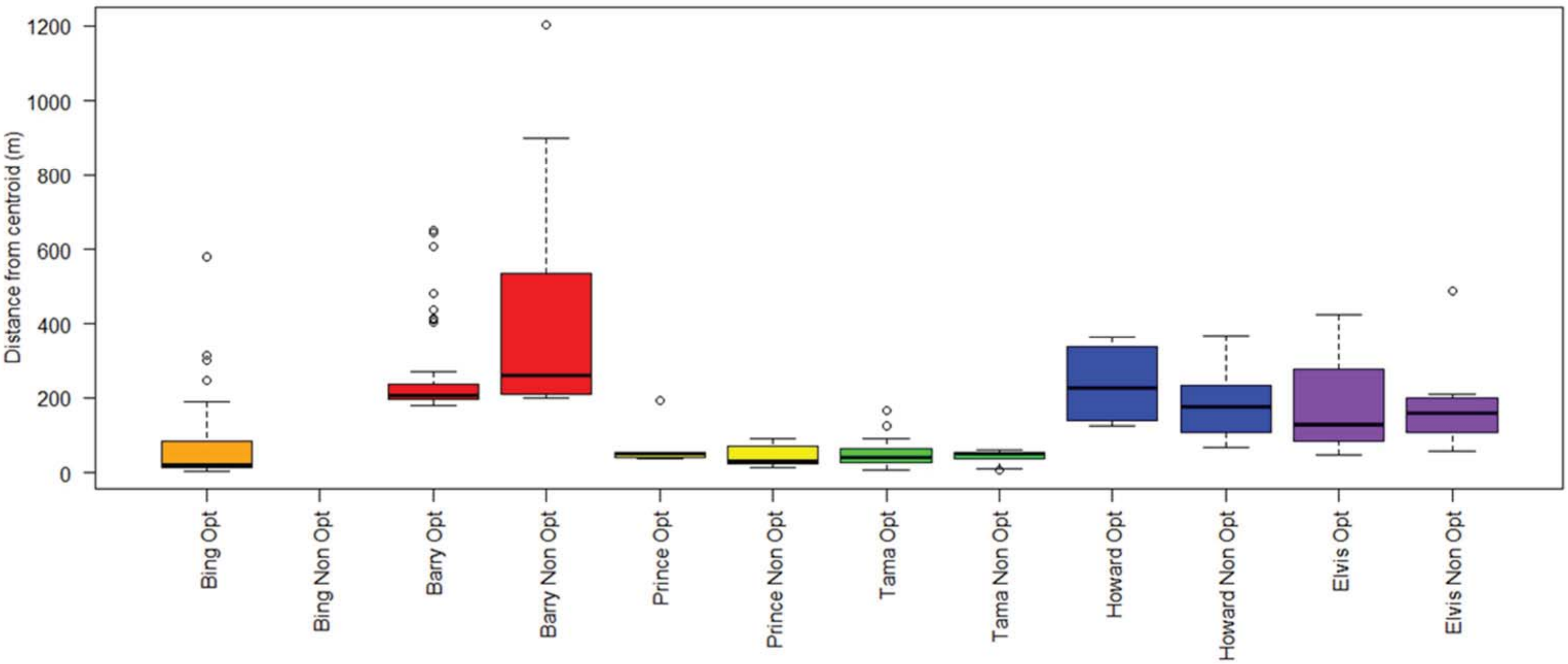

Figure 6.3: Distance moved from centroid of 95% Utilisation Distribution for six marked bitterns at Lake Whatumā. Distances were classed into two time periods, one representing the optimum time of year to monitor bitterns (3 September to 14 November, 'Opt') and the other representing later data (14 November to 3 December, 'Non Opt'). No 'data were available for Bing after the optimum period because he permanently left the lake mid-way through the breeding season.

6.3.2. Core booming territories of marked and unmarked bitterns

The majority of booms detected by the expert observers could be classed into 11 discrete core booming locations, including a core territory for each marked bittern (86% of 246 calls, Figure 6.4). The remaining 14% of booms could not be confirmed as new territories. This was because: a) the boom was a one-off event and therefore likely to have been produced by transient males or a resident male responding to specific territorial threats (or mate responses) or, b) in the case of unmarked birds, uncertainty existed as to whether the calls were from a new bird or a neighbouring unmarked bird. For example, booms heard in core territories 3 and 4 (Figure 6.4) were sometimes within 40 m of each other but because both birds were heard within a single sampling window, calls were assumed to have been from separate unmarked birds. Similarly, booming was heard north of core territory 7 but these were not classed as being from a different territory because such calls were never heard within the same sampling window as booming in core territory 7 (Figure 6.4).

All 11 core booming locations were compact in area (mean size 0.84 ha, SD 0.27, Table 6.1) with a high proportion of the total number of booms from most marked bitterns falling into a low proportion of their respective UDs (> 0.67 of total booms fell within < 0.08 of the birds UD, Table 6.1, Figure 6.5). Exceptions to this were Tama and Prince. However, the UDs of these two bitterns were particularly small anyway, meaning that even though booming for these two bitterns was spread more evenly across the UDs of these birds (> 0.67 total booms fell within 0.33 and 0.54 respectively, Table 6.1), core booming territories were still small and comparable with those of the other bitterns (Figure 6.5). No marked bitterns were observed booming in any other bittern’s core booming territory (marked or unmarked, Figure 6.5) but three marked bitterns (Elvis, Howard and Barry) and two unmarked bitterns were detected booming within the overlapping region of Elvis and Howard’s UDs towards end of the breeding season (> 11 November, Figure 6.5). Additionally, the UDs of Howard and Elvis overlapped the core booming range of one unmarked bird (Core booming territory 8, Figure 6.5).

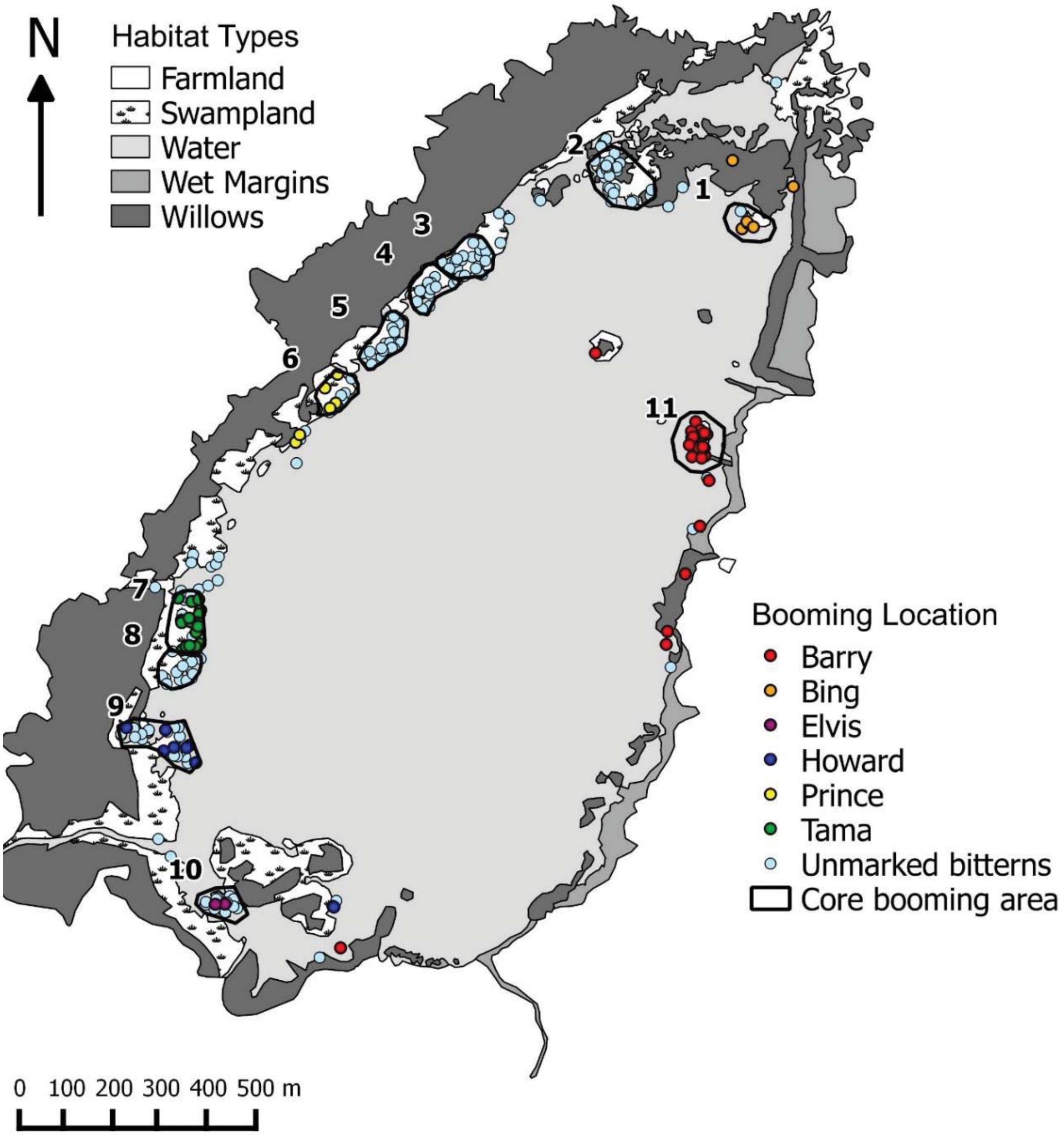

Figure 6.4: Core booming territories and booming locations for bitterns at Lake Whatumā between September and November 2014. Core territories were defined using the 'expert opinion' method.

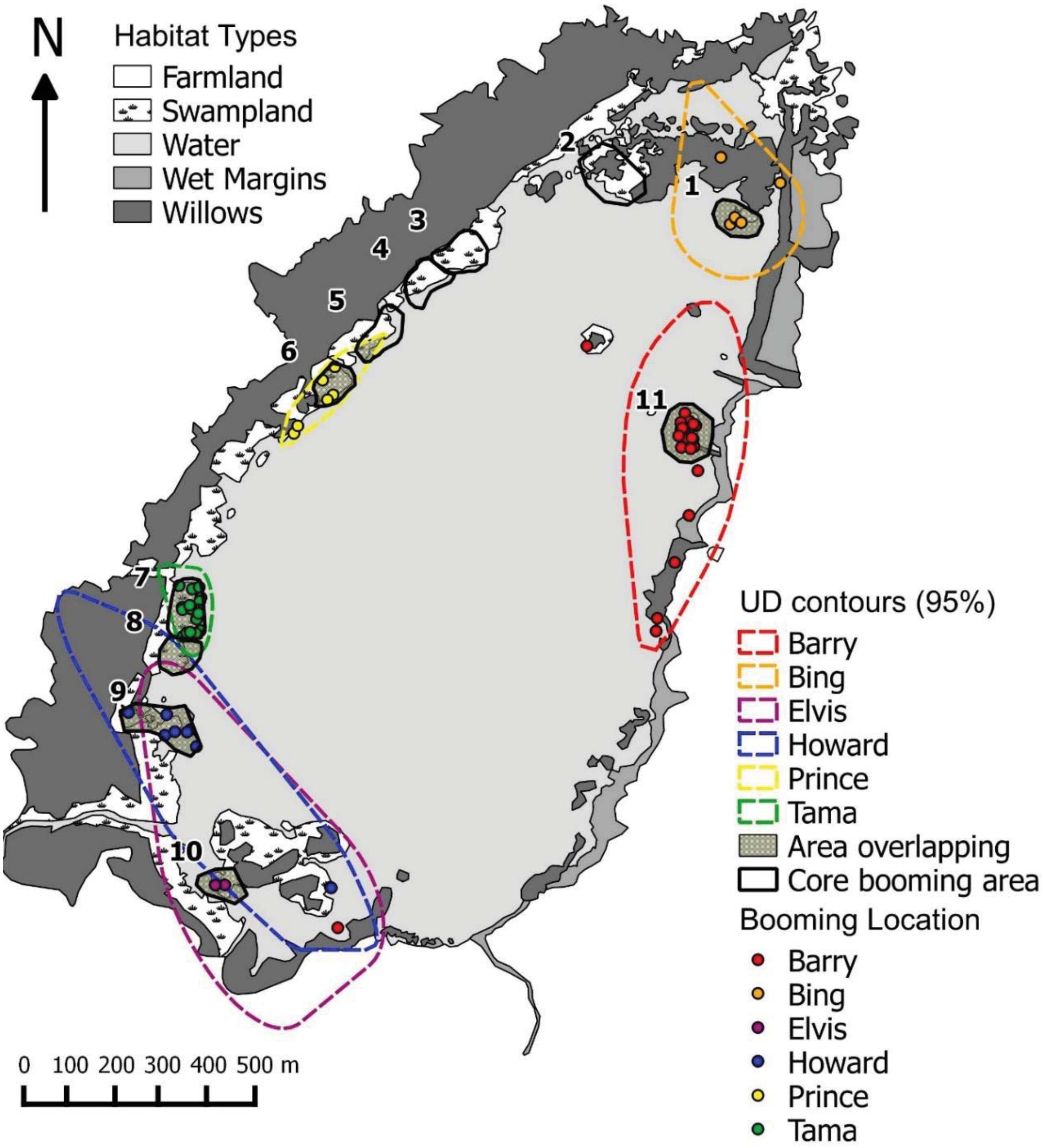

Figure 6.5: Proportion of overlap in area between the 95% Utilisation Distributions of marked bitterns and the core booming territories of all other bitterns (marked and unmarked) at Lake Whatumā between September and December 2014.

6.3.3. Comparison of monitoring estimates

Expert observers recorded a maximum of 12 booming males at Lake Whatumā across the entire season. However, all 12 birds were only available to be detected by the naïve observers during September monitoring, as only 10 males could be confirmed to be present on the lake from October onwards. This was because one marked bittern (Bing Crosby) left the lake between 15 and 17 October. The other bird (Greybeard), who was unmarked, but had a distinctive call, was heard booming south of Barry White's territory but also disappeared in early October, prior to the October naïve monitoring period. This bird may have returned periodically to boom on the lake but is not plotted on Figure 6.4 because booming was too infrequent for expert observers to confirm a territory. The mean number of male bitterns detected during acoustic triangulation counts was 10.5 (± 3.11 SD, n = 4 counts) for September, 8.5 (± 2.65 SD, N = 4 counts) for October, and 8.25 (± 1.71 SD, n = 4 counts) for November (Figure 6.6). The mean number of male bitterns detected during close approaches was nine (± 1.73 SD, n = 3 counts) for September and six (only one count) for October. Samples sizes for close approaches were smaller in October and absent from November because high winds between midday and sunset made kayaking too hazardous on the lake (Figure 6.7).

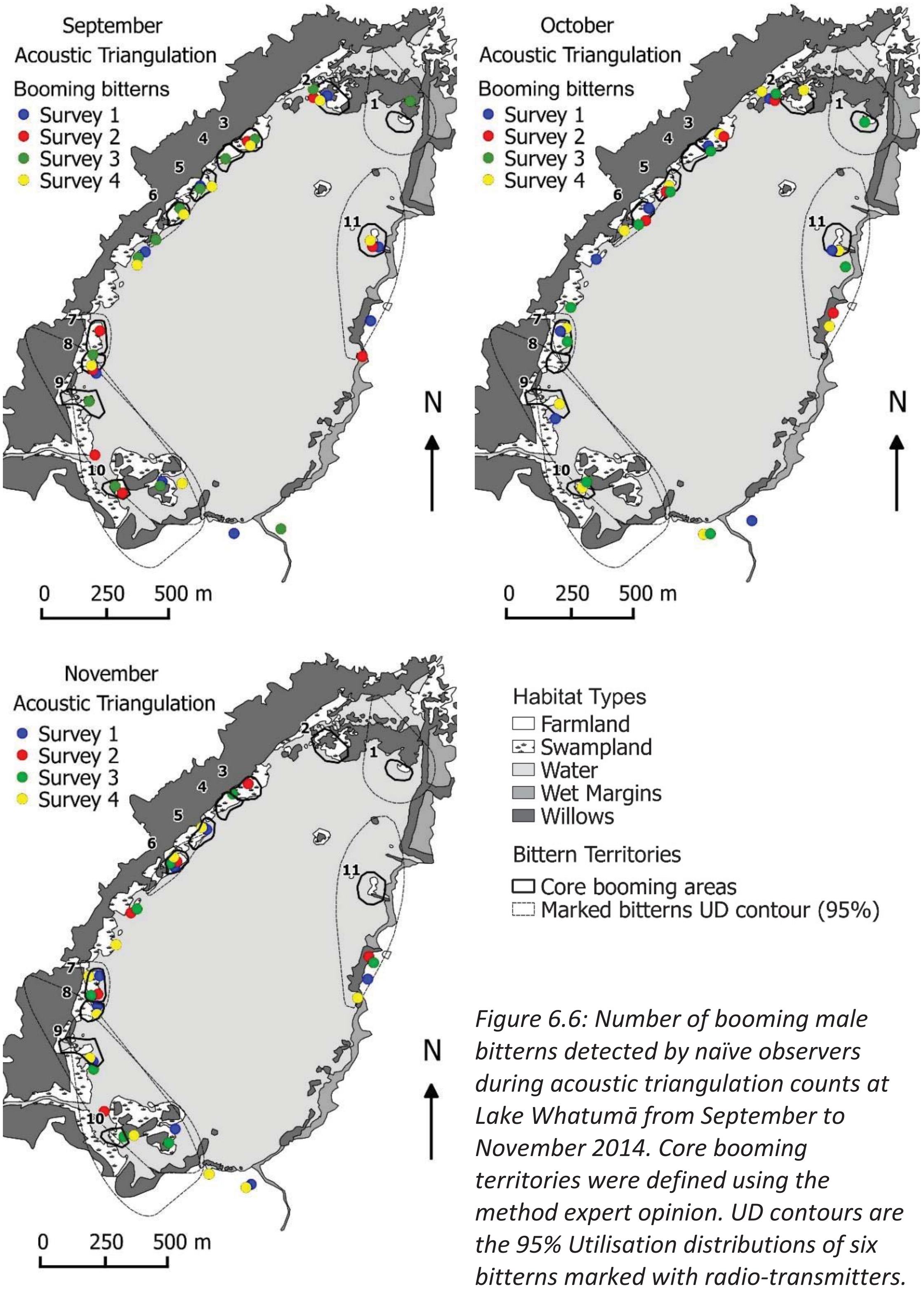

Figure 6.6: Number of booming male bitterns detected by naïve observers during acoustic triangulation counts at Lake Whatumā from September to November 2014. Core booming territories were defined using the method expert opinion. UD contours are the 95% Utilisation distributions of six bitterns marked with radio-transmitters.

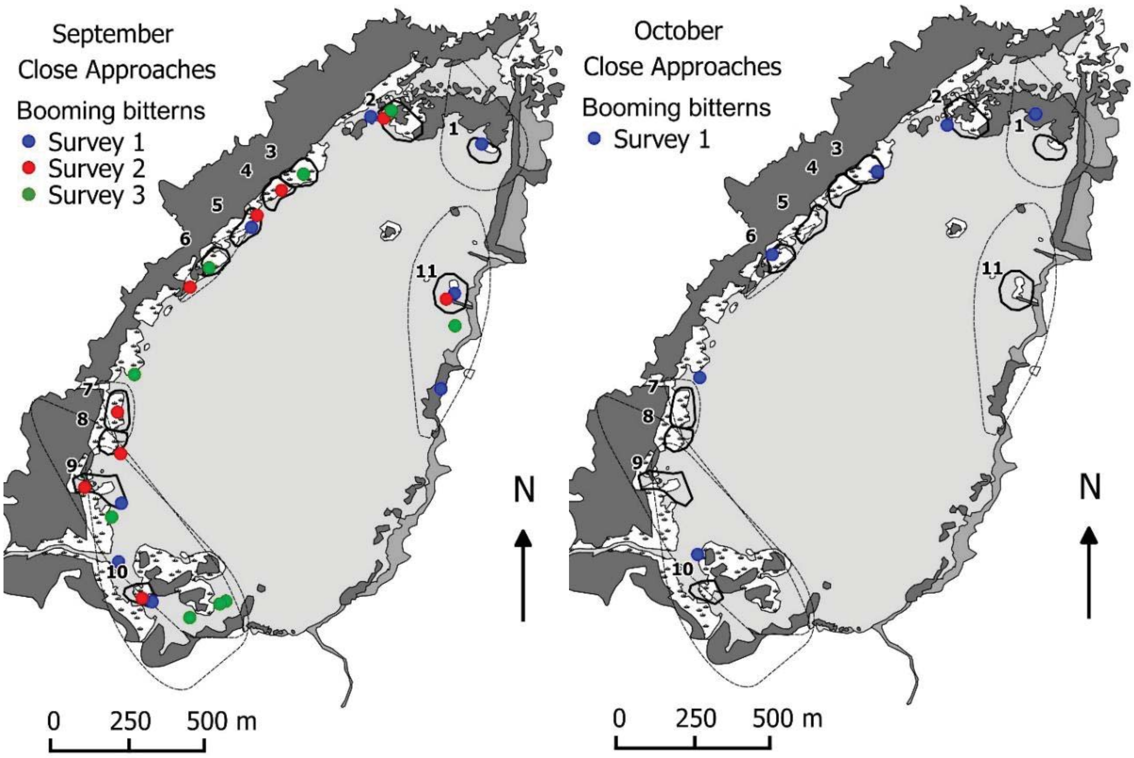

Figure 6.7: Number of booming male bitterns detected by naïve observers during close approaches counts at Lake Whatumā from September to October 2014. Core booming territories were defined using the method expert opinion (solid lines and numbers 1-11). UD contours are the 95% Utilisation distributions of six bitterns marked with radio-transmitters (dashed lines).

6.4. Discussion

Acoustic territory-mapping methods are commonly used to monitor cryptic species, particularly those with long-ranging calls that inhabit inaccessible areas or areas of dense vegetation (Budka & Kokociński, 2015). Such methods are useful because they can account for individuals not detected within single counting periods (when used appropriately) - something that point counts cannot do. Yet the resources they require are similar to those of point counts. However, the appropriateness of any territory-mapping method depends upon the behaviour of the target species (Bibby *et al.*, 1992; Thompson *et al.*, 1998), and in particular the assumption that individuals have high site fidelity (Bibby *et al.*, 1992; Sutherland *et al.*, 2004).

Territory-mapping is a common method used on Eurasian bitterns, *Botaurus stellarus*, and little bitterns (*Ixobrychus minutus*) (Chapter 2). Many of these territory-mapping studies acknowledge that their methods are subject to the assumptions tested here

(Poulin & Lefebvre, 2003; Van Turnhout *et al.*, 2006) but this is the first study to test these assumptions throughout monitoring periods. Similarly, home range data for all *Botaurus* species are scarce, and largely limited to post-breeding movements (Puglisi *et al.*, 2003; Lor, 2007), with only one study reporting bittern movements during the breeding season (Puglisi *et al.*, 2003).

Booming at Lake Whatumā occurred in discrete territories, the locations of which were consistent across methods. Furthermore, observations of the six marked bitterns suggest that booms detected within these discrete territories were produced by the same individuals even when the Utilisation Distributions of these individuals overlap. This suggests that the majority of individuals can be distinguished via their booming territories without the need for physical marking; allowing the size of male breeding (booming) populations to be estimated by mapping these territories.

Despite this result, care should still be taken when relying upon this assumption. The purpose of booming is thought to be territory defence and mate attraction (Teal, 1989), meaning that territory size is likely to change with breeding status and stage. This concern is supported by the expansion of Barry White's territory later in the breeding season. Bitterns were marked progressively across the season, meaning that birds marked later in the season had smaller sample sizes than those that were marked throughout. Barry White was the first bittern to be marked and, therefore, the bird with the largest sample size. It is possible that the territories of those bitterns marked later also expanded towards the end of the season, but that this temporal correlation was not discernible because too few samples were available for these birds at the beginning of the season.

Overall, the Utilisation Distributions of male bitterns at Whatumā were small but variable (mean = 12.46 ha, ± 10.16 SD, Table 6.1). However, sample sizes of at least four of the marked bitterns were lower than is recommended for kernel density analysis (< 30 fixes; Bing Crosby = 28 fixes; Howard Morrison = 27 fixes; Prince Tui Teka = 20 fixes and Elvis Presley = 12 fixes) (Seaman *et al.*, 1999; Laver & Kelly, 2008). Despite these small sample sizes, UDs calculated in this study were similar to those of two Australasian bitterns (8 ha ± 2.83) studied during one booming season at Whangamarino wetland, Waikato (Teal, 1989), although it is not clear which methods Teal (1989) used to obtain these values.

Eurasian bitterns also display sedentary behaviours during the breeding season, although they appear to have larger Utilisation Distributions than those found in this study. For example, the mean Utilization Distribution of male Eurasian bitterns at Lake Massaciuccoli, Italy, calculated with analytical methods similar to ours (95% Kernel Density, LSCV smoother, was 43.5 ha (27.0-108.7) (Puglisi *et al.*, 2003). This difference could be attributed to the lower density of bitterns at Lake Massaciuccoli, which has 7-25 booming males within 800 ha (year dependant), in comparison to Whatumā which has 13 booming males within < 250 ha.

Like this study, booming activity in Italy occurred predominately within males' core territories (5.7 ha, 75% cluster analysis), with some infrequent booms occurring at scattered locations outside this range (Puglisi *et al.*, 2003). Some overlapping occurred between 75% Utilisation Distributions with *B. stellaris* (0-12% overlap, *n* = 9 individuals, Kernel density analysis, LSCV smoother). However, these occurrences were rare and largely attributed to a few birds that were 'never present at the same spot simultaneously' (Puglisi *et al.*, 2003). It's not clear from Puglisi *et al*. (2003) whether overlaps in Utilisation Distributions were limited to the beginning or end of the season, or if they involved booming events. In the study presented here, similar overlapping events occurred with two of the bitterns marked towards the end of the season (Howards and Elvis). Similarly five birds were heard booming within the overlapping area of these two marked birds Utilisation Distributions towards the end of the season (> 11 November). The lateness of these observations with respect to the breeding season suggests that these overlaps may be associated with the creation and breakdown of territories, rather than being something of the norm. If this is the case then they are less likely to affect abilities to estimate male breeding bittern populations.

In conclusion, the majority of marked bitterns observed in this study had high site fidelity during the breeding season. Furthermore, booming behaviours from marked bitterns matched those expected of unmarked bitterns (when it's assumed that booms consistently produced from the same small, discrete, core-booming areas are the same individual). This suggests that territory mapping methods are appropriate for use on this species. However, the emigration of two bitterns (one marked and one unmarked) from the study area during the breeding seasons suggest that high site fidelity cannot be assured for all individuals.

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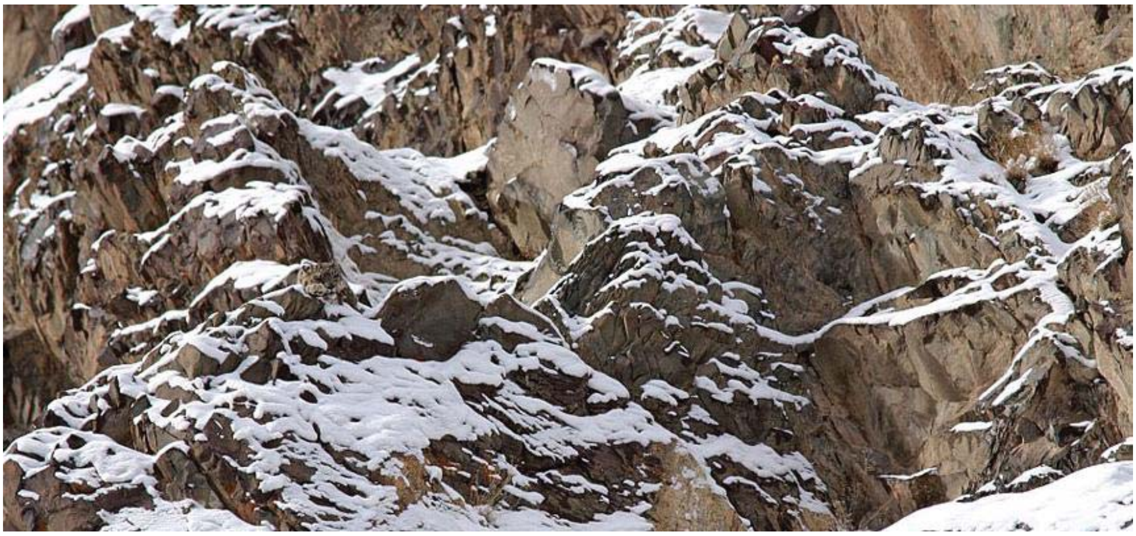
7

General Discussion



Upper image: A snow leopard, Uncia uncia, relaxing on a rock (mid left).
Credit: Raghu Chundawat.
Lower image: A wolf, Canis lupus, emerging from behind a tree (top left).
Credit: Fun.marinov.net.

7.1. Introduction

In this thesis, I examined cryptic characteristics and monitoring challenges, across multiple species and classes, to allow development of several monitoring methods that could be used on Australasian bitterns. To my knowledge, this is the first study to examine the range of monitoring challenges that are being reported across difficult to detect species and attempt to class these challenges into a set of cryptic characteristics. In Chapter 1, I demonstrated that two species-specific characteristics and two logistical site-specific characteristics restricted monitoring of Australasian bitterns in New Zealand. All of these characteristics were shared with other cryptic species (Chapter 1 and 2), and identifying and separating these characteristics allowed them to be tackled as separate experiments, making them easier to address.

In this chapter, I discuss why Australasian bitterns have ended up in a 'too hard basket' in terms of estimating absolute abundance, and how the approach used in this thesis may help to liberate other species from similar metaphorical baskets. To demonstrate this further, I use the example of the Guam rail, *Gallirallus owstoni*, to show how similar challenges can be approached with another cryptic species. Additionally, I discuss some of the limitations of the work presented in this thesis, and how these challenges are currently being addressed through related ongoing work. Finally, I discuss the importance and implications of monitoring Australasian bitterns, and how this knowledge is helping conserve the species.

7.2. 7.2 Developing a monitoring method for a bird that looks and behaves like a plant – starting at the beginning

Work towards developing a monitoring method for Australasian bitterns started in 2003 with Pierce (2004), who trialled a call-count method at Whangamarino wetland in the Waikato region. In 2005, the Department of Conservation reviewed this method and concluded that data had high spatial and temporal variability, and were difficult to interpret (IMU, 2005; Holzapfel, 2006). Furthermore, power analysis that I undertook showed that the method proposed by Pierce (2004), which involved call-counts at ten locations, had insufficient power to detect a change in calling-rate of less than 10%

within 5 years (Appendix 6), meaning that the method was unlikely to suit the purposes of managers of Whangamarino wetland at the time (Matthew Brady, Department of Conservation, *pers. comm.*). Power could be improved by increasing the number of stations sampled and therefore coverage, something that at the time was logistically impossible in this 7100 ha wetland using a people-based monitoring method (Chapter 4 and Appendix 6). This led to the work in chapters 3 and 4 of this thesis. These chapters tackle these logistical site-specific characteristics by identifying factors affecting call-count variability and examining recording devices as a solution to spatial crypsis.

7.3. Key findings of this thesis and what it tells us about cryptic species in the 'too hard basket'

The primary aim of this thesis was to determine whether any concepts involved in the process of developing a monitoring method for specific cryptic species could be applied more generally across species. The four cryptic characteristics identified through reviewing 30 publications were not necessarily experienced by all cryptic species but certainly extended across classes, suggesting that solutions may also be shared (Table 1.1, Chapter 1).

One of the most common challenges experienced while monitoring cryptic species was low and/or highly variable detection probabilities (Table 1.1, Chapter 1). Such challenges are a concern because they can bias inferences about trends (Chapter 1). This is why it is important to use monitoring methods that account for detection probabilities with cryptic species. Yet, surprisingly few cryptic species appear to be monitored using such methods.

Detectability, and how it affects the performance of monitoring methods, is not a new concept. Indeed, a literature search in Scopus using the terms 'monitoring', 'species' and 'detectability', within the subject area of 'Biological Science', showed that the topic was being discussed as far back as 1989 (Figure 7.1). So why is it that so few cryptic species are being monitored using these methods?

The Australasian bittern nicely illustrates how, and why, detection probabilities are not always accounted for in monitoring practises. In Chapter 2, I demonstrated that bitterns are renowned for being difficult to detect, with similar cryptic characteristics being reported across both *Botaurinae* genera (*Botaurus* and *Ixobrychus*, Table 2.1). Effectively, this sub-family represents the extreme of crypsis, as all 12 species have most of the characteristics identified in the review presented in Chapter 1, which examined cryptic characteristics across multiple species and classes (Chapter 2). With this degree of crypsis, it would be logical to assume that most monitoring practises used on bittern species would account for variable detection probabilities. Yet, Chapter 2 showed that the majority of bittern species are monitored using index counts or best guess – two methods that are entirely unable to measure or account for any changes in detection probabilities (Table 2.2, Chapter 2).

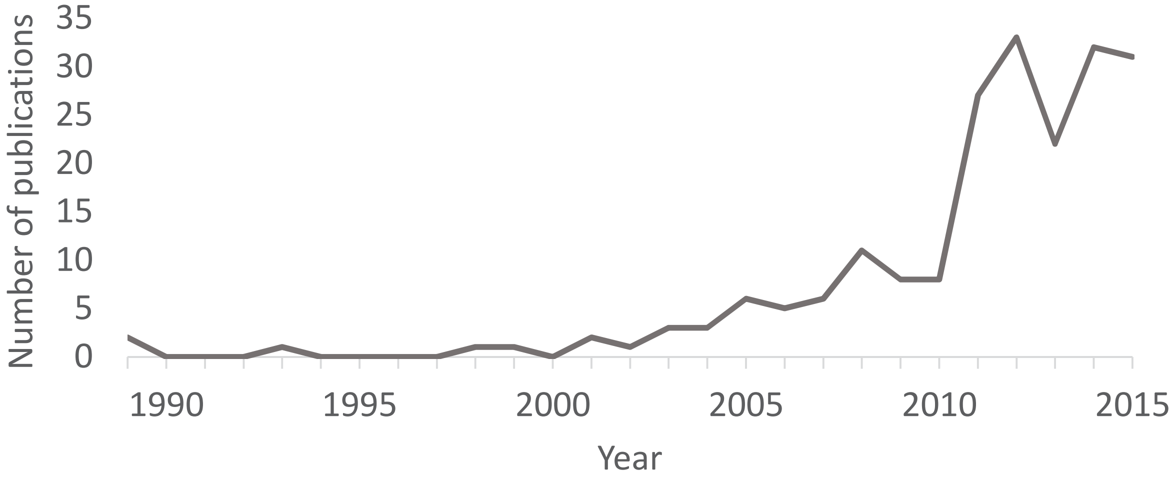


Figure 7.1: Frequency of publications that acknowledge or discuss detection probabilities with regard to monitoring wildlife. Publications were found using the search terms ‘monitoring’, ‘species’ and ‘detectability’, within the subject area of ‘Biological Science’, in Scopus.

There are several possible reasons why detection probabilities have remained unaccounted for with most methods used on bittern species. To start with, bitterns have not received much monitoring attention, so methods being used are not very diverse. Publications on almost half of *Botaurinae* species report either no monitoring or basic inventory/best-guess surveys intended to determine the status of these species (5 out of 12 species or 42%; Table 2.2). This appears to be changing, and more recently there has been a sudden appearance of publications that use modelling to answer more complex questions regarding the needs of bittern species (e.g. Jobin *et al.*, 2013; Kasprzykowski & Polak, 2014; Pickens & King, 2014; Camp *et al.*, 2015).

Another possibility is that there have not been the tools or knowledge to solve many of the monitoring problems associated with bitterns. Detectability, and the need to account for it in monitoring practises, has only picked up momentum in the last 10 years (90% of publications < 10 years old, Figure 7.1). As the majority of *Botaurinae* publications are more than 10 years old (58%; Table 2.2, Chapter 2), it is likely that these tools were not accessible when most of the methods being used on bitterns were being designed.

Many of the tools used in this thesis to solve the monitoring problems experienced on Australasian bitterns were not new but have recently become more accessible. For example, recording devices had already been used to solve some monitoring problems experienced with cryptic species like the Cory's Shearwater (*Calonectris diomedea*), the black drum (*Pogonias cromis*), and the African forest elephant (*Loxodonta africana cyclotis*) (Goh, 2001; Thompson *et al.*, 2009; Locascio & Mann, 2011). However, Chapter 4 is the first study to show that these devices facilitate monitoring practises for cryptic species that would otherwise be too costly and impractical. In the case of Australasian bitterns, recorders can allow the use of sampling regimes that have greater power to detect population changes, than would be possible using more conventional methods (Chapter 4).

Likewise, similar modelling techniques to those used in Chapter 3 and 5, have already been used to generate detection probabilities from replicated call-count data, therefore allowing inferences regarding the number of individuals not detected (MacKenzie *et al.*, 2002; Williams *et al.*, 2002; Royle & Nichols, 2003; MacKenzie & Nichols, 2004; Kéry *et al.*, 2005; Pellet & Schmidt, 2005; Bailey *et al.*, 2007; Rota, 2009; Moreno & Lele, 2010). However, my study is the first attempt to generate numbers of individuals from calling-rate, therefore potentially allowing abundance estimates in situations where recording devices present the only option feasible for monitoring (Chapter 4 and 5).

Equally, the need to understand factors that affect detectability with call-count methods is well publicised but most studies addressed these challenges by examining each predictor of calling-rate separately (e.g. Gibbs & Melvin, 1993; Conway *et al.*, 2004).

Identifying predictors in this way can be problematic in ecological studies, as variables inevitably correlated. This correlation confounds true effects unless all variables are considered together. The recent accessibility of hierarchical modelling is one way to solve this problem, as hierarchical modelling enables random effects to be identified and estimated while accounting for all other effects in the same model, theoretically providing more accurate effect sizes (Chapter 3 and 5).

Thus the ability to liberate Australasian bitterns from the ‘too hard basket’ has been possible because of combined advances in several areas i.e. modelling practises are more accessible to ecologists, methods that measure and account for imperfect detection probabilities are more readily accepted and available; and acoustic equipment is much cheaper and therefore more accessible for use in wildlife studies. Modelling and theories regarding detectability were particularly important for addressing the two species-specific characteristics identified in Chapter 1. This is because they enabled predictions regarding the optimum times to detect bitterns, which can either be used to standardise methods or adjust counts to predict abundance (Chapter 3 and 4). Similarly, it was only the availability of low cost recording devices that enabled logistical site-specific characteristics to be solved and provide the option of predicting abundance at sites that were difficult to access (Chapter 4 and 5).

Despite this, advances in developing monitoring methods are still limited without knowledge of the natural behaviours of the target species. Obtaining behavioural data for cryptic species can be particularly challenging as these species are also often data deficient (Clarke *et al.*, 2003). In the case of Australasian bitterns, it was only possible to put results from Chapters 1, 2, 3, 4 and 5 into true context when I started to capture, handle and follow bitterns. As Chapter 5 and 6 show, the usefulness of any monitoring method depends on its assumptions and, therefore, it is important to ensure that assumptions are reasonable in terms of the natural behaviours of the target species (Bibby *et al.*, 1992; Thompson *et al.*, 1998).

7.4. How to apply the approach used in this thesis to another cryptic species

The process of separating cryptic challenges into four cryptic characteristics is likely to be useful when developing monitoring methods for other cryptic species. This is because cryptic characteristics are shared across different species and classes, meaning solutions can also be shared. To illustrate this, I was invited to go over to Guam in December 2014 to look at the monitoring challenges being experienced with the Guam rail, and determine whether the approach used in this thesis could be applied to this situation. This section briefly summarises what was learned during this trip, and how I'd approach any future work towards developing monitoring methods for this species.

The Guam rail (Plate 7.1) is a flightless bird endemic to Guam that became extinct in the wild in 1987 due to predation by brown tree snakes, *Boiga irregularis,* (Savidge, 1987; Wiles *et al.*, 2003; BirdLife International, 2012). However, after a successful captive-rearing program, Guam rails have been introduced into the wild in two locations: 1) Cocos Island, a small island to the south of Guam that is only accessible via ferry – the availability of which is controlled by a variable tourist industry – and 2) Rota island, which forms part of the Northern Mariana Islands, and is only accessible via several intermittently available flights (Brock & Beauprez, 2000; Suzanne Medina, *pers. comm.*; Fontenot *et al.*, 2006; Division of Aquatic and Wildlife Resources, 2012). Evidence of breeding has been observed in both populations but due to the remoteness of these areas, little is known about population numbers (Sherley, 2001; Suzanne Medina, *pers. comm.*). Therefore, there is a need to develop a reliable monitoring method that can determine population trends and establish whether reintroductions have been successful (e.g. populations are self-sustaining) (Suzanne Medina, *pers. comm.*).

Currently Guam rail populations are monitored through call-counts that involve eliciting responses of birds using playback. However, the probability of a bird responding to playback appears to vary in response to unknown factors (*pers. obs.*). This is likely to confound true population trends making them difficult to interpret (Chapter 1). Additionally, the remoteness of both populations and infrequency of transportation limits any possibility of measuring playback-responses over a broader time scale. This makes it difficult to standardise monitoring practises and determine if monitoring is occurring at the optimum time. Currently there is no mark-recapture method available that is known to work on the species, and birds hide in thick vegetation making them difficult to see (*own obs.*).

In keeping with the approach used to develop methods for monitoring Australasian bitterns, the following objectives are recommended:

1) Review potential monitoring methods for Guam rails and their feasibility (Chapter 2). Here it may be useful to start with methods already used on other rail and crake species but also include species that have similar cryptic challenges to those identified for the Guam rail (Table 7.1, Chapter 1).

2) Identify factors affecting response-rates of Guam rails to playback and model effect sizes of these factors over a broader range of times and environmental conditions (see Chapter 3). This will allow current monitoring practises to be standardised, but may also provide the ability to estimate abundance (Chapter 5). Note that the ability to estimate abundance will depend upon which predictors of response-rate are identified as important, the strength of the model selection process, and the quality of the data used in the model (Chapter 5).

3) Investigate any available tools that can be used to overcome the logistical restrictions currently experienced when accessing Cocos Island and Rota Island. Recording devices in particular are likely to be useful if call-based methods continue to be pursued (Chapter 4).

4) Investigate the feasibility of alternative cues for detecting the species. Call-based methods may not be the best methods to use on this species and alternatives may prove more useful depending upon behaviours of the species, i.e. scent, heat or motion detection methods (Chapter 2, and Section 7.5 below).

5) Investigate the feasibility of several capture methods that could be used as part of a mark-recapture study and/or to confirm assumptions of monitoring methods in relation to natural behaviours of the species (Chapter 6). These should become more obvious as work proceeds. However, a good place to start is with cues used to attract, or find, members of the opposite sex, as part of pair bonding and breeding.

Plate 7.1: A Guam rail at the captive rearing facility in Guam.

Table 7.1: Summary of monitoring constraints associated with Guam rails. Ticks (✓) denote a restriction that is found with the species and question marks denote a restriction where there is insufficient information to know if the restriction applies

			Restriction (✓= restriction caused by cryptic characteristic)			
			Small sample size	Low detections	Variable detection probabilities	Data biased by sampling regime
Species characteristics	**Visually cryptic**	Small size		✓		
		Looks[*]		✓		
		Well hidden[1]		✓		
	Behaviourally cryptic	Low activity		✓		
		Vocally cryptic e.g. short, quiet calls		✓		
		Solitary or sparsely distributed		✓	✓	
		Secretive or evasive		✓		
		Small or large home ranges		?	?	
		Highly mobile[α]				
Logistical characteristics	**Spatially cryptic**	Specialist equipment or skills[δ]				
		High cost	✓			✓
		Access is taxing or time consuming[δ]	✓			✓
	Temporally cryptic	Nocturnal or crepuscular			?	?
		Seasonally detectable			?	?

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[*] Looks or appearance e.g. well camouflaged in relation to the environment; [1] Well-hidden e.g. inhabits areas with thick vegetation or lives in burrows; [α] Highly mobile e.g. moves quickly between sampled sites; [δ] Access is difficult e.g. requires specialist equipment and/or or skills.

7.5. Key findings made during related ongoing work

A major disadvantage of monitoring bitterns using booms is that these calls are only produced by males of breeding age. This is not a problem if male breeding bittern populations are indicative of changes across the broader bittern population. However, realistically this is not likely to be the case. Australasian bitterns have several characteristics that suggest that females may be more vulnerable than males, and juvenile recruitment has the potential to be low. For example, females are ground nesters, entirely responsible for incubation, and approximately one third smaller than males, probably making them one of the most vulnerable wetland birds to predation (O'Donnell *et al.*, 2015).

Very little is known about breeding behaviour and breeding success, but research to-date suggests females lay relatively few eggs per clutch (mean ≈ 4), and have one clutch per season (Teal, 1989; Marchant & Higgins, 1990; Heather & Robertson, 1996; O'Donnell, 2011). This implies that juvenile recruitment and the populations' capacity to recover may be slow, especially if adults are not long-lived. Additionally, predation is not likely to be the only threat. Bittern species overseas experience multiple threats, many of which are also found in New Zealand (O'Donnell, 2011). Indeed, only one juvenile (< 1 year old) and one adult female have been caught and radio-tagged to-date, allowing them to be followed to a known fate. Sadly, both of these bitterns died of starvation < 2 months after release (Williams & Brady, 2014; E. Williams unpubl. data).

Thus, there is a need to develop a method that can provide information about population numbers and growth for females and juveniles, as well as males. To do this three alternative cues are available that can be used to detect bitterns as part of a method. These include: thermal imagery, motion cameras and use of dogs as scent detectors (Chapter 2). Although the use of these cues is not specifically covered in previous chapters, all three cues were trialled (albeit haphazardly) on bitterns at Lake Whatumā between September and December in 2014 and 2015. These trials involved first locating a radio-tagged bittern using the TR-4 and Yagi aerial, so that its location was known, and then attempting to re-find that bird using one of these three alternative cue detection methods.

Feasibility of these alternative cues varied and all three need more work to conclusively determine whether they are worth pursing as options. However, observations so far suggest dogs have the most potential. The dog used to trial detection via scent was a four year old Labrador-cross called Kimi. Kimi was originally cued in on bittern scent using feathers and positive reinforcement. Since becoming 'cued-in' she has accompanied me in the field most days while doing survey work and while tracking radio-tagged bitterns as part of the site fidelity study (Chapter 6). During this period she has shown great potential in picking up live bittern scent through the thick vegetation from a kayak (Plate 7.2), and while wading through the water (Plate 7.3). Kimi has also been able to assist in catching bitterns by hand, by leading me to radio-tagged bitterns that were hiding in the thick vegetation. This appears to work because, when approached, bitterns have a tendency to hide in the thick vegetation, rather than flushing (the latter is perhaps more risky to the bird as it reveals their location) (Plate 7.4). This makes them easy to catch once their location has been revealed by the dog. To-date, Kimi has assisted me with eight hand-captures of four different bitterns (three radio-tagged birds and one unmarked bird). We still need to obtain a lot more experience in order to become a highly skilled team. However, experiences to date have contributed to us being able to pass our full conservation dog certification on 4 December 2015. Despite these successes, the dog's ability to determine direction sometimes appears compromised in the thick vegetation. This is not a problem if the dog has the freedom to work the scent to the source, but could limit the use of dogs in inaccessible areas where the dog's movements are restricted.

Plate 7.2: Emma and Kimi look for radio-tagged bitterns from a kayak at Lake Whatumā. Credit: John Cheyne.

Plate 7.3: Emma and Kimi wading back to the kayak after finding a radio-tagged bittern in thick raupō (Typha sp) at Lake Whatumā. Credit: Andrew Glaser.

Plate 7.4: A juvenile female bittern at Harts creek, Lake Ellesmere, Canterbury, demonstrates the posture regularly observed when working a dog to detect bitterns. This posture, involving the bird crouching low and remaining very still in the dense Typha vegetation, makes them almost impossible to see, but easy to catch once its location has been revealed by a dog. Credit: E. Williams.

To-date, motion detectors (trail cameras) have successfully captured several images of bitterns (Plate 2.1, Plate 7.5), particularly when they were left out along existing tracks in areas where bitterns were known to regularly boom. In contrast, attempts to 'see' bitterns using an FLIR Scout-2 thermal handheld imagery camera were unsuccessful. This was attempted on three occasions: one an hour before sunrise, another during daylight hours, and the third after the sun had set. During all three attempts, birds were in the thick raupō (*Typha orientalis*), which obscured the camera's ability to detect any infra-red. Chances of success could perhaps be improved by aerially looking for bitterns, as the males boom from open platforms (Teal, 1989) and therefore may be more easily distinguished. Alternatively, birds may be detectable via infra-red at other sites where raupō is less prevalent.

Plate 7.5: An unmarked Australasian bittern captured on a trail camera within the territory of another marked male at Lake Whatumā, Hawkes Bay, New Zealand. Credit: Lake Whatumā care group.

7.6. Implications for the conservation of Australasian bitterns

There is currently no management or recovery plan for the conservation of Australasian bitterns in New Zealand. Australasian bitterns are classed as Endangered by the IUCN and Nationally Endangered in New Zealand because numbers are thought to have drastically reduced throughout their range due to habitat loss (Miskelly *et al.*, 2008; Buchanan, 2009; BirdLife International, 2014). Interestingly, in New Zealand, many species receive higher conservation efforts than Australasian bitterns, yet have a lower threat classification. While conservation efforts for these species are undoubtedly well deserved, it is a concern that species that have been identified as being at a higher risk are so easily, and completely, overlooked. The perception that Australasian bitterns are hard to work on could be one reason why this species has been ranked as a low priority. This is especially likely given that some authors argue for a resource prioritisation system that weighs ‘cost’ and ‘probability of success’ higher than ‘threat ranking’ (i.e. Joseph *et al.*, 2008). Other reasons for why little work has been conducted on Australasian bitterns are not publicised, but from my experience the following problems may have contributed to Australasian bitterns affording little attention:

1) Bitterns have a low public profile. Aside from the birding community, most of the New Zealand general public do not know what a bittern is. It is possible that this is due to the cryptic nature of the species rather than lack of interest. The majority of landowners that I met while radio-tracking bitterns seemed very excited and surprised to learn that they have the rarest *Botaurinae* species in the world on their land. Yet it was only because of the radio-tag that we knew that the bittern was present on their land.

2) Bittern habitat (wetlands) is also undervalued and land conflicts mean wetlands are readily destroyed (Johnson & Gerbeaux, 2004). Raising the profile of their habitat will also help bittern conservation.

Results from this thesis are already helping to address some of these challenges by showing that work on bitterns is achievable. Results from Chapter 3 and 4 have already been used to inform monitoring protocols that are being applied nationally (O'Donnell & Williams, 2015). The primary purpose of O'Donnell & Williams’ (2015) protocols was to liberate Australasian bitterns from managers' 'too hard baskets' by providing easy-to-use cheap methods for detecting and monitoring bitterns that can be used on a low budget by anyone. These methods are considered current 'best practise' but are by no means comprehensive (and were never intended to be). Indeed the spatial and temporal variation that remained unaccounted for in Chapter 3 already suggests that several factors, which were not considered in any of the models, may be affect bittern calling-rates. Additionally, at the time that O'Donnell & Williams (2015) was published, methods and results from this thesis still needed to be tested at sites outside of Whangamarino wetland before results could be considered nationally applicable. Results from Chapters 5 and 6 are a start to this process.

Examples of groups using these protocols include:

- Friends of Mangarakau. This project is keen to show the response of bittern populations to predator control at Managarakau wetland in Golden Bay (Robyn Jones, *pers. comm*).
- The Arawai Kakariki wetland restoration programme. This programme is using methods from the protocols to monitor changes in bittern populations in response to a new predator control regimes at Awarua-Waituna wetland in Southland (Sarah Thorne, Senior Biodiversity Ranger, *pers. comm.)*, and Whangamarino wetland in the Waikato region (Kaitlin Morrison, Biodiversity Ranger, *pers. comm.).*
- The Department of Conservation Dargaville district office. This office has initiated some new monitoring to inventory bittern populations at several wetlands around the Kaipara region (Oliver Knox, Biodiversity Services Ranger, *pers. comm*).
- The Department of Conservation Opotiki office. This office has been using recording devices to understand more about how and where bittern populations are distributed in the Bay of Plenty region (Mithuna Sothieson, Biodiversity Ranger, *pers. comm.*).
- Project Janszoon is using recording devices to inventory bittern populations at various sites within Abel Tasman National Park (Ingrid Hutzler, *pers. comm.*).

- Lake Whatumā Care Group. This group of local landowners wish to show responses in bittern populations following willow and predator control at Lake Whatumā (John Cheyne, Ducks Unlimited, NZ President, *pers. comm.*).

Improvements made to monitoring practises of Australasian bitterns, as a result of this study, should create data that are more informative in terms of project objectives. Hopefully, this will enable managers and community groups to show population changes within a shorter time-frame, and therefore react more quickly when interventions are required. Furthermore, the knowledge gained in this thesis can be applied to a range of methods, therefore allowing managers to answer a wider variety of questions about bittern populations under their jurisdiction. This is an important first step towards reversing declines of Australasian bittern populations, as it allows threats to be correctly identified, and provides information about the effectiveness of management practises. Additionally, this thesis has demonstrated that work on Australasian bitterns is feasible. The more work that is done on bitterns the higher the profile of the species, and the greater the chances of achieving the awareness and support that is required to secure the persistence of this quirky but delightful bird.

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8

Appendices

A sketched Australasian bittern. Credit: Jono More

Appendix 1

Declaration confirming content of digital version of thesis

I confirm that the content of the digital version of this thesis

Developing monitoring methods for cryptic species: A case study of the Australasian bittern, *Botaurus poiciloptilus*

is the final amended version following the examination process and is

identical to this hard-bound paper copy.

Have you published articles/material from your thesis?

~~Yes /~~ No

If yes, have you received copyright permission from the copyright holder, (usually the publisher), to include this material with your thesis?

N/A

Emma M. Williams

14 January 2016

Appendix 2

Criteria for recording climate variables during bittern counts[1]

Noise

Low—Light background noises:

- Short/loud noises are brief and rare (e.g. banging doors, occasional car or other birds calling).
- Continuous noises are quiet and not distracting (e.g. light drone of vehicles on motorway and/or train).
- Overall the observer does not feel distracted or have problems concentrating. Feels that no calls are being missed even if the calling bird is very far away. Both short/loud noises and continuous noises are easy to ignore.

Med—Some background noises:

- Short/loud noises occur regularly and last longer than 30 seconds each time.
- Continuous noises are constant and loud enough that calls made far away may be missed.
- Overall the observer feels that some quiet calls may be being missed and may have trouble concentrating (e.g. tormented by the occasional mosquito).

High—Lots of background noises:

- Short/loud noises are regular and very distracting (e.g. geese/other waterfowl constantly gaggling, people talking or shouting).
- Continuous noises are loud and close by (e.g. running water, nearby highway, annoying mosquitoes0.
- Overall the observer feels continuously distracted and frustrated by noises. Some calls may be missed even if the bird is a medium distance away or close by.

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[1] These criteria are my own work but have been published as part of O'Donnell, C. F. J., & Williams, E. M. (2015). Protocols for the inventory and monitoring of populations of the endangered Australasian bittern (Botaurus poiciloptilus) in New Zealand. DoC Technical Series 38. Wellington: New Zealand Department of Conservation.

Wind strength

Calm—May be able to feel a light breeze on the face, but branches and leaves are largely still or only move slightly.

Light—An occasional or constant breeze, but only light branches and leaves are affected. Leaves may rustle slightly but the noise is not distracting.

Moderate—Small branches move and sway. Leaves rustle but the wind is less than 10 knots. There is a constant wind.

Strong—Gusty, with large branches and leaves swaying. Rain is at a 45^o angle or less.

Moon visibility

1—Not visible, completely covered by clouds.

2—Visible, completely covered and likely to stay that way for the majority of the survey.

3—Visible, partially covered and likely to stay that way for the majority of the survey.

4—Visible, no cloud.

D/K—Don’t know; cannot see the moon because it has not risen or a physical feature is in the way (e.g. trees, hill or building).

N/R—Not recorded.

Appendix 3

Table A3.1: Relationships considered during exploratory analysis of the calling rate of Australasian Bitterns in Whangamarino wetland in 2009 and 2010, squares ☐ show form of relationships that were compared, with ticks (☑) denoting the superior relationship based on improvements in Deviance Information Criteria values (Chapter 3).

	Relationships explored				
Variable	Linear	Binary	Categorical	Polynomial (up to 7th order)	Random
Month	☐		☑		
Time of day	☐		☑	☐	
Water levels	☑				
Rainfall	☑	☐			
Cloud cover	☑				
Moon phase	☑				
Moon visibility	☑				
Wind speed	☑				
Temperature	☑				
Noise	☑				
Year		☑			
Observer effect			☑		☐
Observation period ID					☑
Location (station)					☑

Appendix 4

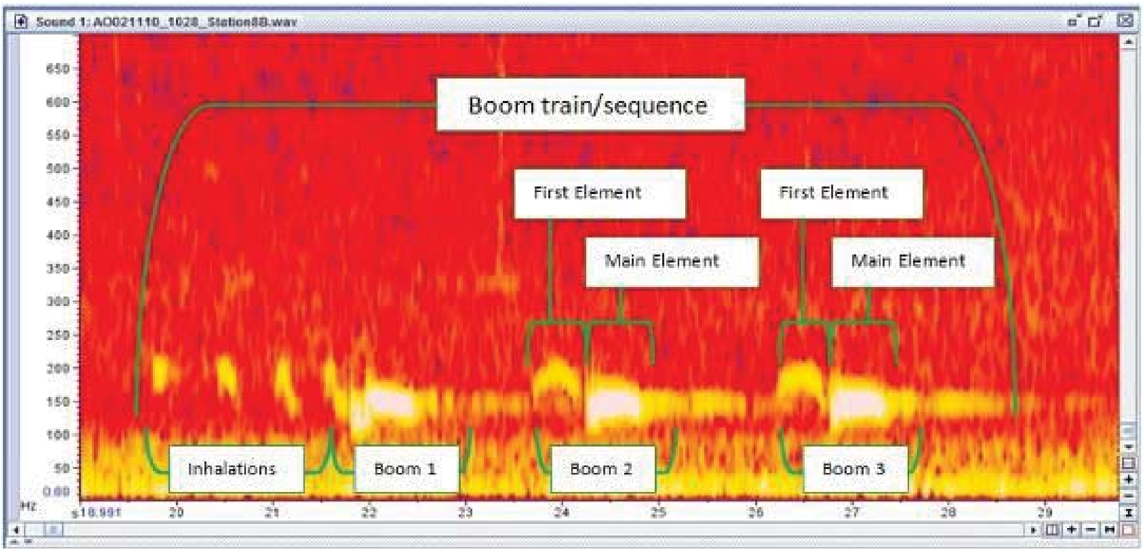
Comparison of betas for the top models

Table A4.1: Beta values for the simplified model (Model 1i), where sd is the standard deviation of the β estimate, 2.5% and 97.5% are the confidence intervals of the β estimates and ΔCRPI is the proportional change in calling-rate (exponential of the β estimate).

				Simplified model (Model 1i)				
Parameter			**Notation**	**β**	**sd**	**2.5%**	**97.5%**	**ΔCRPI**
September			mo[3]	0	0	0	0	0
October			mo[2]	-0.41	0.25	-0.91	0.07	0.66
November			mo[3]	-1.25	0.26	-1.77	-0.73	0.29
Time of day (TD)	Time to Sunrise	3:29 to 2:45 before sunrise	SR[1]	0	0	0	0	0
		2:44 to 2:15 before sunrise	SR[2]	0.10	0.16	-0.22	0.42	1.10
		2:14 to 1:45 before sunrise	SR[3]	0.36	0.16	0.06	0.67	1.43
		1:44 to 1:30 before sunrise	SR[4]	-0.05	0.20	-1.43	0.33	0.95
		1:29 to 1:15 before sunrise	SR[5]	0.36	0.16	0.05	0.67	1.43
		1:14 to 1 hr before sunrise	SR[6]	0.51	0.15	0.22	1.80	1.66
		0:59 to 0:45 before sunrise	SR[7]	0.63	0.15	0.34	0.93	1.88
		0:44 to 0:30 before sunrise	SR[8]	0.51	0.15	0.21	0.82	1.67
		0:29 to 0:15 before sunrise	SR[9]	-0.37	0.16	-0.68	-0.04	0.69
		0:14 to sunrise	SR[10]	-0.73	0.18	-1.07	-0.38	0.48
		0:01 to 0:15 after sunrise	SR[11]	-0.50	0.20	-0.89	-0.11	0.61
		0:16 to 0:30 after sunrise	SR[12]	-0.76	0.20	-1.14	-0.37	0.47
		0:31 to 00:45 after sunrise	SR[13]	-0.72	0.29	-1.29	-0.17	0.49
		00:46 to 1:30 after sunrise	SR[14]	-1.20	0.26	-1.71	-0.69	0.30
	Time to Sunset	1:44 to 1:15 before sunset	SSadj[1]	-1.79	0.27	-2.32	-1.26	0.17
		1:14 to 1hr before sunset	SSadj[2]	-1.39	0.27	-1.92	-0.86	0.25
		0:59 to 0:45 before sunset	SSadj[3]	-1.06	0.24	-1.55	-0.58	0.35
		0:44 to 0:30 before sunset	SSadj[4]	-0.63	0.24	-1.10	-0.17	0.53
		0:29 to 0:15 before sunset	SSadj[5]	-0.89	0.23	-1.34	-0.44	0.41
		0:14 before sunset to sunset	SSadj[6]	-0.49	0.23	-0.94	-0.03	0.61
		0:01 to 0:15 after sunset	SSadj[7]	-0.50	0.23	-0.95	-0.05	0.61
		0:16 to 0:30 after sunset	SSadj[8]	-0.15	0.23	-0.60	0.30	0.86
		0:31 to 0:45 after sunset	SSadj[9]	-0.53	0.23	-0.99	-0.08	0.59
		0:46 to 01 hr after sunset	SSadj[10]	-0.83	0.24	-1.30	-0.36	0.43
		01:01 to 01:15 after sunset	SSadj[11]	-1.26	0.25	-1.75	-0.77	0.28
		01:16 to 01:30 after sunset	SSadj[12]	-1.15	0.26	-1.66	-0.64	0.32
		-01:31 to 2:15 after sunset	SSadj[13]	-0.80	0.24	-1.27	-0.32	0.45
Rain			Rn	-0.21	0.06	-0.34	-0.10	0.81
Moon Visibility			MV	0.44	0.18	0.09	0.79	1.55
Observation period ID			PID	0.61	0.08	0.49	0.78	1.85
Location/Station			stn	0.32	0.05	0.24	0.42	1.38

Appendix 5

Figure A5.1: Spectrogram of an Australasian bittern boom sequence showing the terms used to describe and identify bittern calls. Boom sequences often, but not always, consist of multiple booms that are preceded by a series of inhalations (or pumps). Each individual boom within a sequence is made up of a first element and main element. Terms used here are in keeping with descriptions provided for the vocalisations of the Eurasian bittern (Gilbert et al. 1994[2]). Spectrogram was produced using Raven Pro (Bioacoustics Research Program 2011) with 0-30 seconds on the x-axis, 0-700 Hz on the y-axis and a sharpness setting of 2792 (Chapter 4).



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[2] Gilbert, G., McGregor, P., & Tyler, G. (1994). Vocal individuality as a census tool: practical considerations illustrated by a study of two rare species. *Journal of Field Ornithology, 65*(3), 335-348.

Appendix 6

Instructions for using automatic Acoustic Recording Devices (ARDs) (Ver B.2) for monitoring Australasian bitterns (*Botaurus poiciloptilus*)[3]

Equipment

1–20 × automatic Acoustic Recording Device (Ver B.2) (available from the DOC Electronics Laboratory, Wellington,electronics@doc.govt.nz)

1 x 8-GB SD card per recording unit

4 x AA rechargeable batteries per recording unit

How the recorder works

The recorder will automatically wake up at the preset 'Start Time' every day and will start to record continuously for the preset 'Duration Time'. The rest of the time the recorder is asleep and draws very little power.

The sound files

The recordings are stored on the memory card as single channel .wav files in a folder called 'survey'.

Sound files are stored as separate files of 15 min duration. Each file is named with the current date and time (6 digits + 6 digits separated by underscore). For example, a sound file recorded on the 26/02/10 at 9:24:06 PM will be named 260210_212406.wav. The files are also date stamped in the normal way so that the time/date created will appear in File Explorer.

The sound files can be played back on a computer or analysed using sound analysis software.

Batteries

The recorder uses four AA batteries, which can be either standard alkaline or rechargeable NiMH (recommended). High-capacity NiMH (2500+ mAH) batteries should last for over 100 hours of recording at the LOW sampling rate. This could equate to 10 days of 10 hours or 50 days of 2 hours—the time between recordings has little impact on the battery capacity. Batteries can be expected to last for 25 days using sunrise and sunset bittern settings (4 hours per day) provided that an 8-GB memory card is used.

Battery life is dependent on the sampling rate, so only use the HIGH rate for species that require it. Using high sampling rate, the battery life reduces to about 50 hours. Therefore, if you are only targeting bitterns, set the sampling rate to LOW (so that high frequency sounds are not recorded), but if you wish to detect multiple species, e.g. bitterns, marsh crakes and fernbirds, set the sampling rate to HIGH.

Note:

---

[3] These deployment protocols were adapted from Acoustic Recorder Instructions Ver B.2 written by Stuart Cockburn, Department of Conservation, Wellington

- The only way to stop the recorder from running each night is to remove the batteries.
- NiMH batteries will give much longer life and performance if they are always kept, used and charged in sets.

Setting up the recorder

To open the recorder, remove the aluminium (or plastic) tube cover by gently twisting until the locators disengage and then pulling on the cover. Try to ease the tube off rather than allowing it to pull away and bash the recorder electronics inside. Also take care when replacing the cover to ensure that the SD card is not dislodged from its holder.

It is easiest to use your hands to lever the cover off, as shown in Fig. A6.1.

Figure A6.1. Removing the cover of the recorder.

Once the recorder is open, you can see the display screen, control buttons and SD card slot on one side, and the battery holders on the other (Fig. A6.2). Try to avoid getting moisture or debris inside the recorder—use of silicon bead packets will help with this, which can be obtained from the conservation electronics team at the Department of Conservation (electronics@doc.govt.nz).

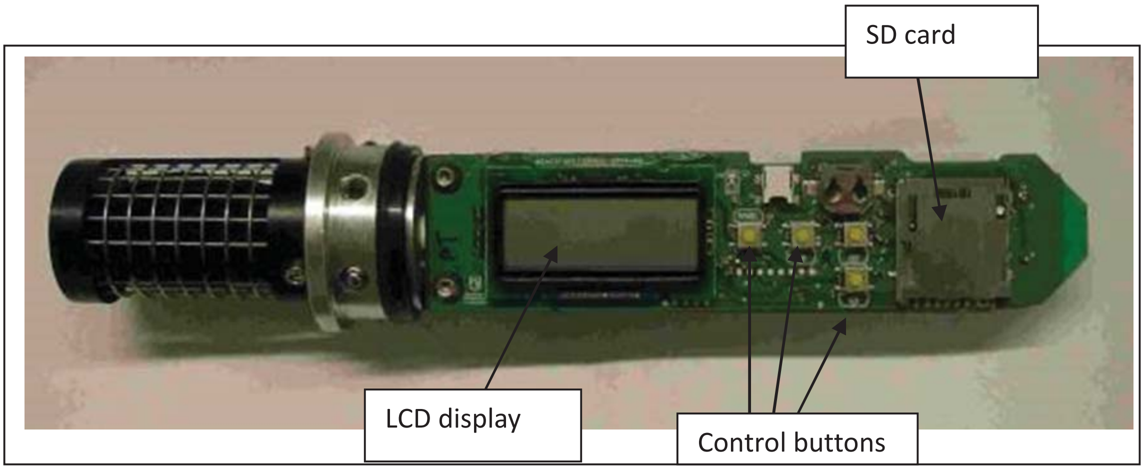

Figure A6.2. View of the inside of a recorder.

Figure A6.3. Mounting the recorder on a tree.

Adjusting the settings

There are four yellow buttons on the recorder to navigate through the menu (Fig. A6.2).

The On/Page key (the left-hand button) wakes up the recorder and cycles through the pages in the menu.

The Plus and Minus keys (+/–) (the two right-hand buttons) modify the settings on the page.

The Shift key (→) (middle button) selects which value to modify.

The settings

Press the 'On/Page' key to start the display. After a few seconds the 'time' page will appear. You can then use the On/Page key to scroll through the various settings pages as outlined below:

Time:	The current time, in 24-hour format.
Date:	The current date, including the year, in DD/MM/YY format.
Start1+Span:	The first start time for recording. The top line is the start time in 24-hour format and the bottom line is the duration. If the duration is set to 00:00 then recording at this time is disabled. For bitterns, set the timer to start 1 hour 30 min before sunrise and set the duration as 02:00.
Start2+Span:	As above, but for a second recording period. For bitterns, set the timer to start 30 min before sunset and set the duration as 02:00.
	Alternatively, if the recorders will only be in the field for < 5 days and storage space for the sound files is not limiting, there is the option of setting 'Start1' and 'Span' to 05:00

	and 23:55, respectively. ’Span’ on the ‘Start2’ page is then set to 00:00 (effectively turning the second timer off). This will produce 24-hour recordings, which can be stored for analysis should a software package become available in the near future.
Sampling:	The audio sampling rate of the recorder. The options are LOW or HIGH. For bitterns only, set the timer to LOW.
Card:	Checks the card (function and free space) or reformats the card.

On each page the Shift key (→; middle button) can be used to select a value (the value flashes) and the Plus/Minus keys can be used to modify it. For example, on the time page use the Shift key to select either hours or min and then use Plus/Minus to change the values.

After about 20 seconds of no activity from the user, the display will power down. If you have not finished adjusting the settings, you may have to wake it up again and continue scrolling through the menu.

Deployment of units for bittern monitoring

The recorders can be mounted on trees or posts (the smaller the better, as large trees can cause unwanted blocking of the sound) using the brackets provided (Fig. A6.3). Each bracket can be attached to a tree using cable ties, screws, string, duct tape or whatever else is available. The recorder then sits in the bracket and is held in place by cable ties. We recommend the use of reusable ties, such as cable ties (e.g. http://nz.element14.com/, part number 1230926) or garden ties (e.g. MCGREGORS twist ties, www.mitre10.co.nz/, part number 153617).

For bittern monitoring, attach units to canes/poles at a height of 1.5 metres. These should then be placed in the wetland at stations 400 metres apart.

Surveys should only be conducted in fair weather conditions (avoid rain or strong wind), and avoid deploying units near potential disturbances such as trains, planes and automobiles.

Appendix 7

Detecting the calls of Australasian bitterns (*Botaurus poiciloptilus*) by visually analysing sound files[4]

A7.1 Choosing a software package

The mono files that are recorded using the Department of Conservation's Acoustic Recording Devices (ARDs) can be visually processed using the free software RavenLite or RavenPro 1.4 (the latter is recommended but is only available for free on a 30-day trial). Depending upon the number of boom sequences recorded and the experience of the analyser, you can reasonably expect a 15-min file to take an average of 6 min to process. The choice of which software package to use will depend upon the volume of sound files needing to be processed and what information the processor requires from the files. In general, the following recommendations can be made:

- **RavenLite** is recommended if you are detecting bittern calls to determine basic presence/absence or require a simple count of the number of calls for only a few files. It is free but you will need to register online to use the software.

- **RavenPro 1.4** is recommended if you need to process a large number of files, as it is much easier to use and has additional features, such as the ability to save a window preset and to process multiple files at the same time. It also allows you to easily obtain additional attributes, such as the energy (dB) or peak power (dB) of a call. Unfortunately, however, it is not free—refer to the website for more details on cost. Note that permission can be sought to trial the software for 30 days and New Zealand is one of the countries listed to qualify for a discount at the time of writing.

A7.2 Downloading the software

Raven software (both RavenLite and RavenPro 1.4) can be downloaded from the Cornell Lab of Ornithology at the following web address:

www.birds.cornell.edu/brp/raven/RavenVersions.html

First download the software and then follow the prompts on the website to get the relevant product licence. A licence is required to access the full functionality of the software regardless of whether it is free or not. As part of this process, you are likely to have to register your name and contact details with Cornell. Refer to the website to complete this process.

For RavenPro 1.4 you should download the 63.0M version for Windows, the 30.9M version for Mac or the 28.9M version for Linux.

A7.3 Opening the sound files (using both RavenLite and RavenPro)

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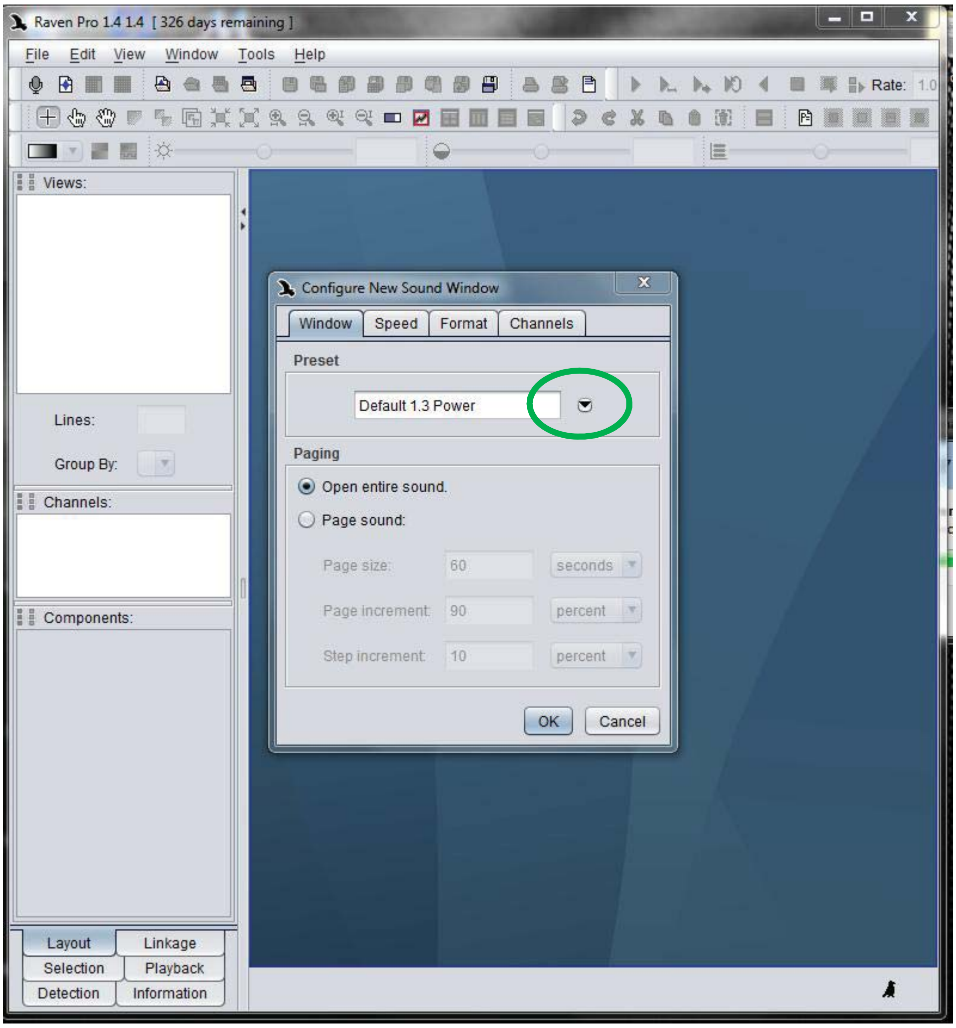
[4] This document is entirely my own work but was published as part of O'Donnell, C. F. J., & Williams, E. M. (2015). *Protocols for the inventory and monitoring of populations of the endangered Australasian bittern (Botaurus poiciloptilus) in New Zealand*. DoC Technical Series 38. Wellington: New Zealand Department of Conservation. View setting from Raven Pro were based on early advice from Murray Efford.

Once the software is installed on your computer and your licence has been verified, you can start to analyse your files. Sound files can be opened in several ways, including:

1. **Traditional method:** Click on File > Open Sound Files and browse through your hard drive until you find the file of interested. Click on your file and then select 'Open'.
2. **Drag and drop method:** On your computer, separately open the folder containing your sound file. Now left click on the sound file of interest, and then drag and drop the file into Raven by holding down your left mouse button.

To get you started we recommend you open the example file provided (ST0032.wav). If this file has not been provided please contact Emma Williams (bittern.wills@yahoo.com) and ask for a copy to be sent to you. Regardless of which of the above methods you used to open your file your screen should now look something like the screenshot in Fig. A7.1.



Raven Pro 1.4 1.4 [326 days remaining]

Configure New Sound Window

Preset: Default 1.3 Power

Paging

● Open entire sound.

○ Page sound:

Page size: 60 seconds

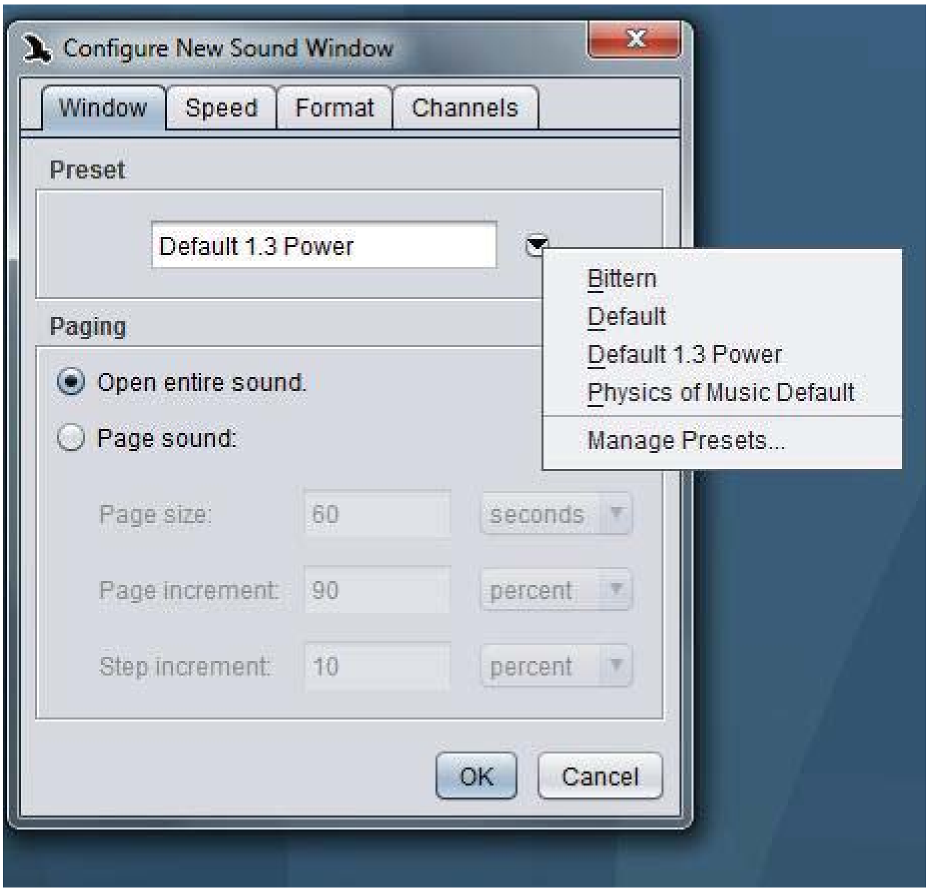
Page increment: 90 percent

Step increment: 10 percent

Figure A7.1. View of starting screen for analysing bittern calls

If you already have a preset window established for bitterns follow instructions (a). If this is your first time processing soundfiles for bitterns then you will not have any presets establish and need to follow instructions (b).

(a) Selecting a preset window. Click on the downward arrow next to the preset box (Green circle, Fig. A7.1). This will bring down a dropdown list of available presets. If bittern is on the list you would click on 'bittern' and then click on 'OK' (Fig. A7.2). Your screen will now look like Fig A7.3, and you are now ready to detect bitterns and can skip to instructions 'Detecting bittern booms' (A7.5).



Configure New Sound Window

Preset: Default 1.3 Power

Paging

● Open entire sound.

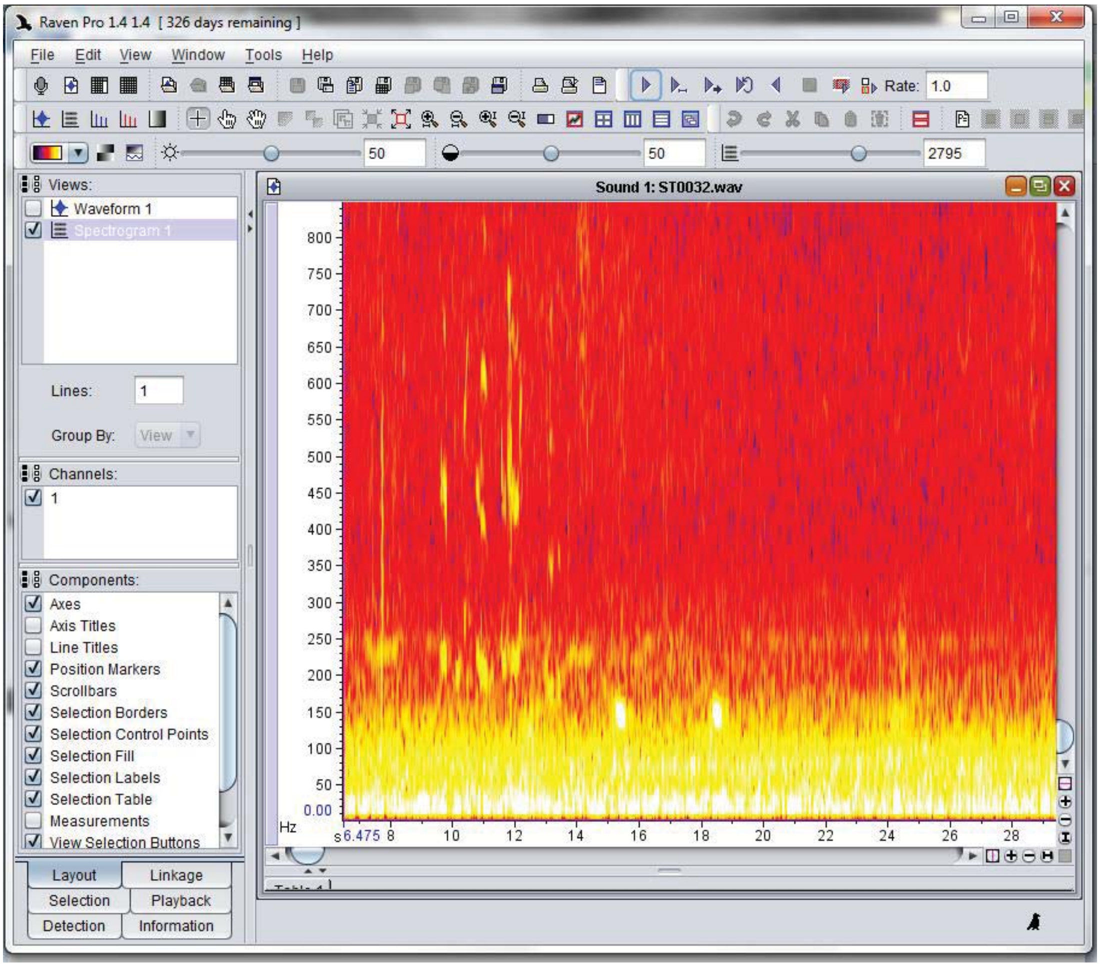
○ Page sound:

Page size: 60 seconds

Page increment: 90 percent

Step increment: 10 percent

Figure A7.2. Drop down list of preset windows



Rate: 1.0

Lines: 1

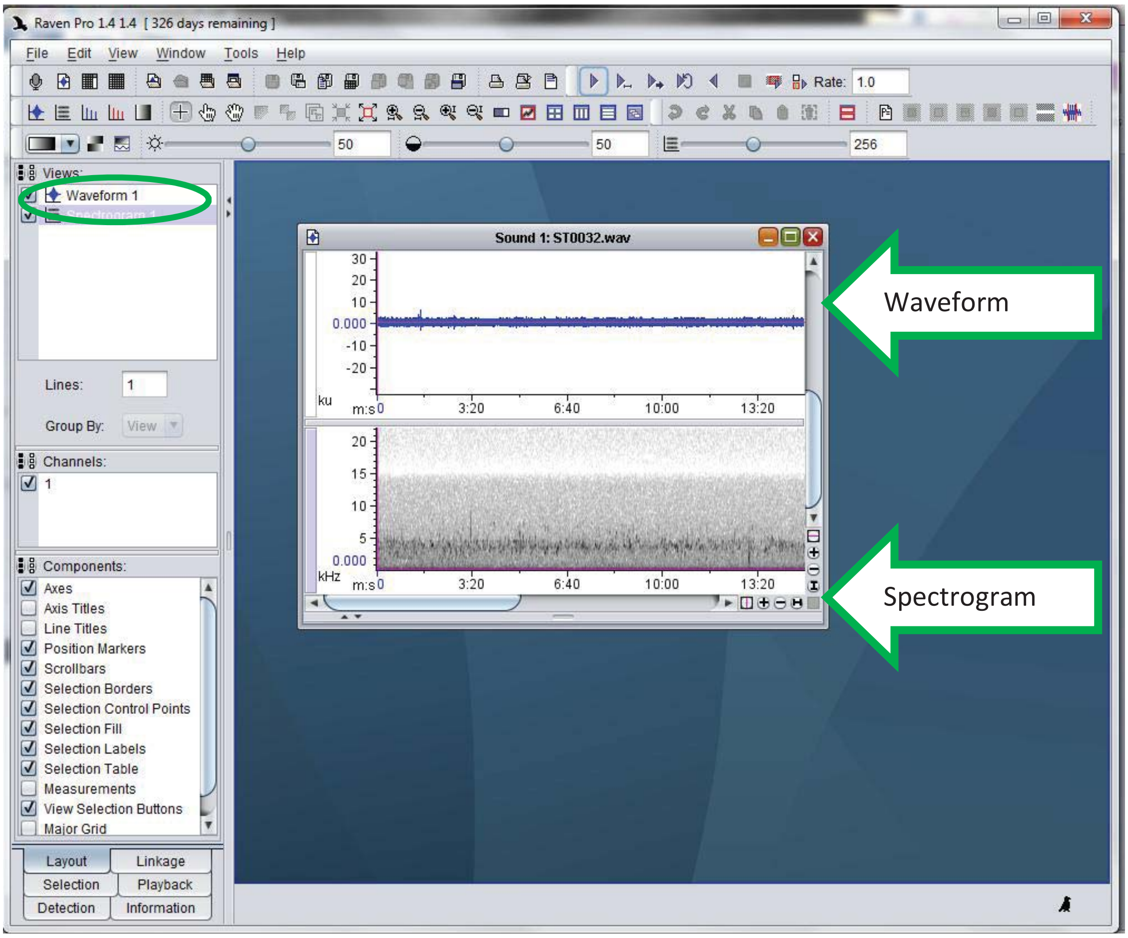
Group By: View

Figure A7.3. View of an open sound file in RavenPro 1.4.

(b) Creating preset window settings to detect bitterns. With your screen looking like Fig. A7.1, Click on 'OK'. Now you should have a screen that looks like the screenshot in Fig. A7.4. Here you are looking at two views (shown by green arrows): the waveform (the upper window with blue lines on a white background) and the spectrogram (the lower window, which appears grey and fuzzy). To prepare your view so that you have the best chance of seeing bittern calls, follow these steps:

1. Turn off the waveform view. To do this, remove the tick that is in the box next to waveform 1 on the left-hand side of your screen (circled in green in Fig. A7.4). Now your screen should look more like the screenshot in Fig. A7.5.

2. Maximise the window by clicking on the button shown by the blue arrow (Fig. A7.5) so that your screen looks like Fig. A7.6.



Rate: 1.0

50 50 256

Views:
☑ Waveform 1
☑ Spectrogram 1

Lines: 1

Group By: View

Channels:
☑ 1

Components:
☑ Axes
☐ Axis Titles
☐ Line Titles
☑ Position Markers
☑ Scrollbars
☑ Selection Borders
☑ Selection Control Points
☑ Selection Fill
☑ Selection Labels
☑ Selection Table
☐ Measurements
☑ View Selection Buttons
☐ Major Grid

Figure A7.4. Creating a preset screen to detect bitterns.

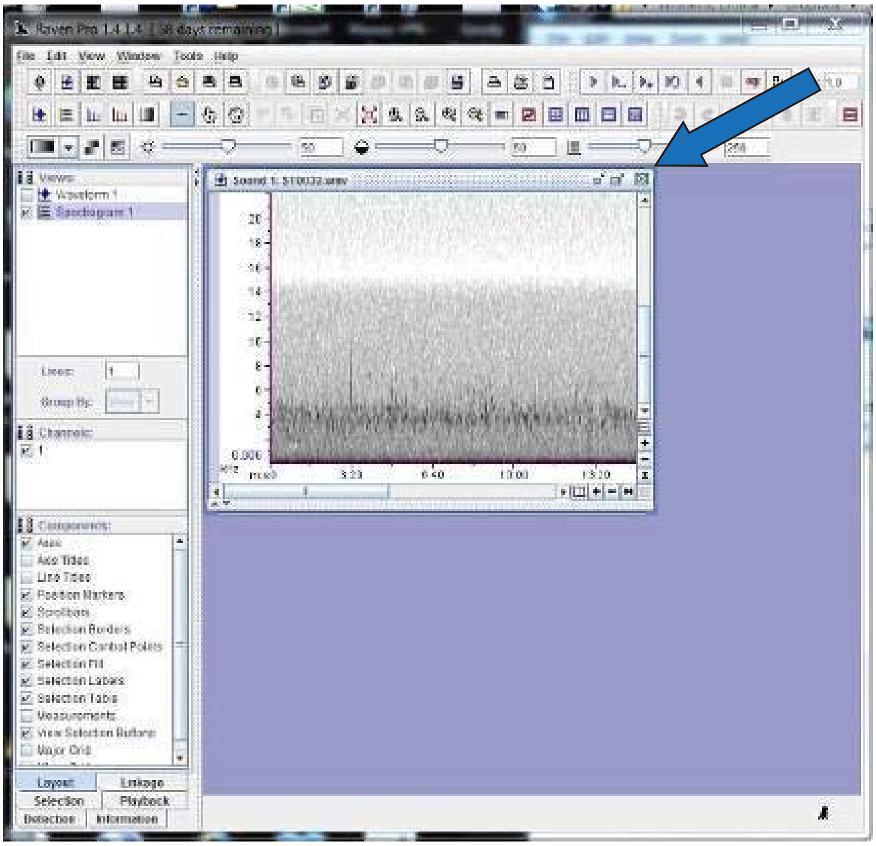


Figure A7.5. View of an open sound file in RavenPro 1.4 only showing the spectrogram.

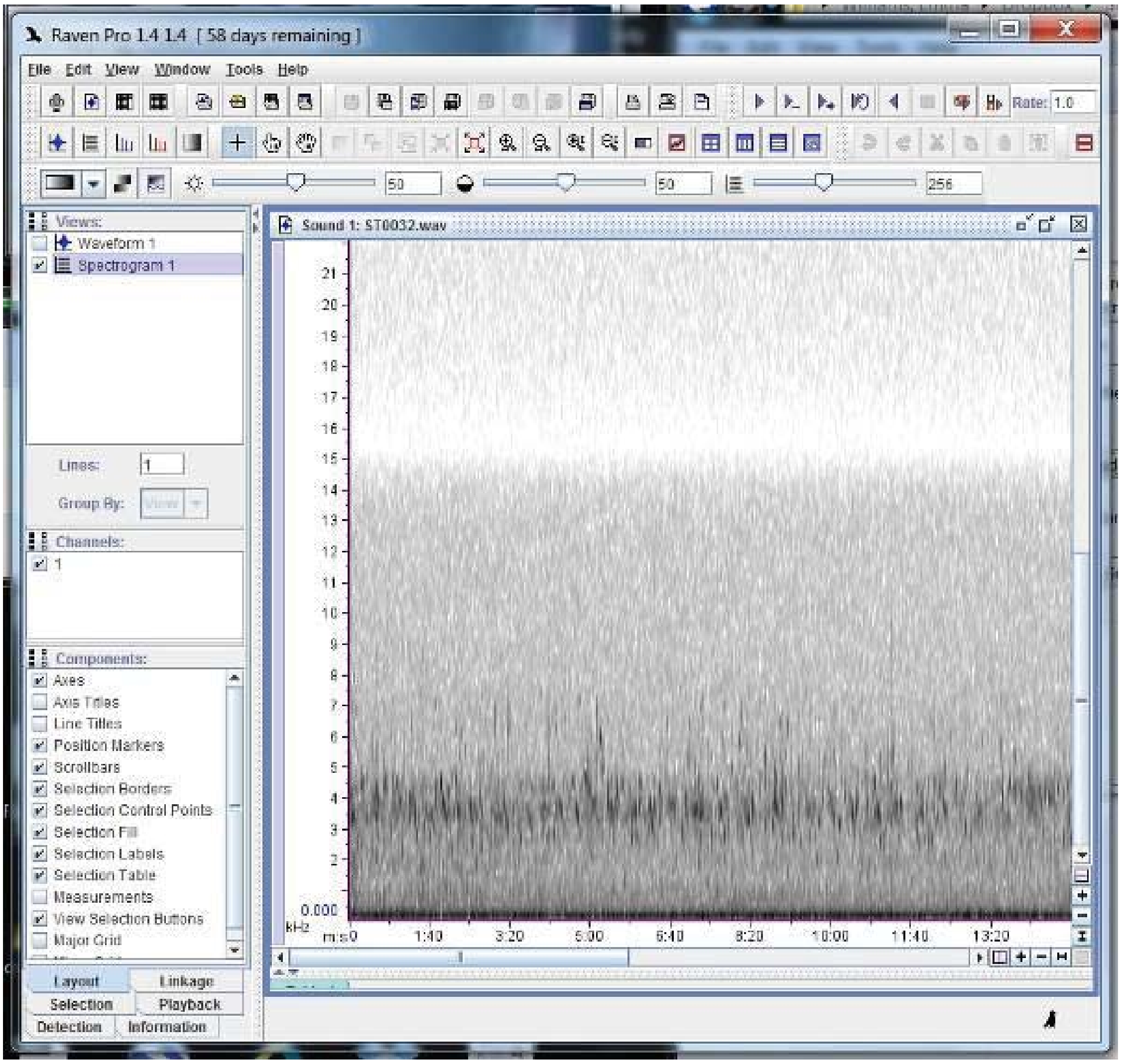
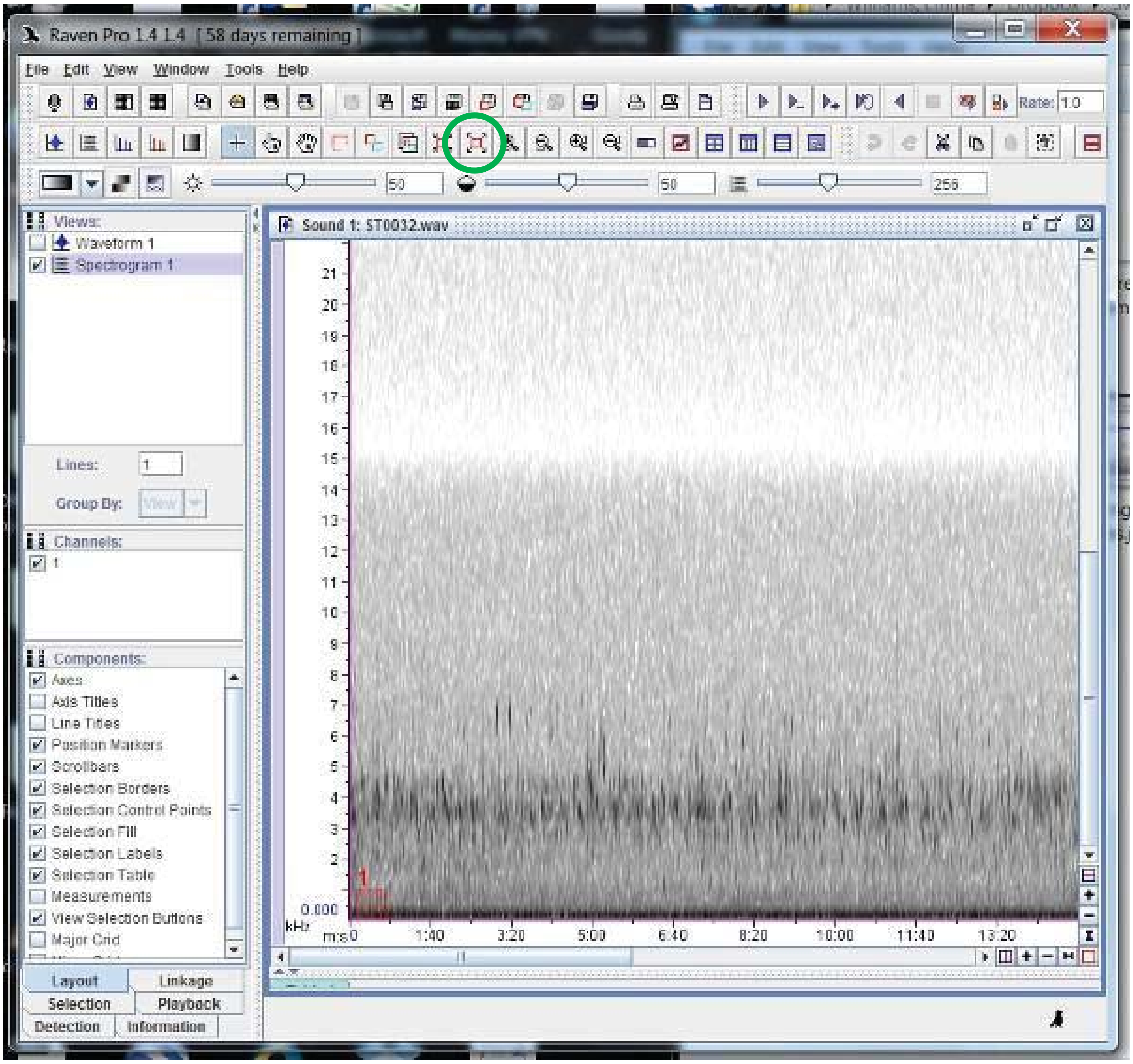


Figure A7.6. View once the waveform has been turned off and screen size maximised.

3. Now set the view so that you are looking at < 900 Hz (y-axis) and 0–30 seconds (*x*-axis). To do this, left click on the spectrogram and, while holding your left mouse button down, draw a box over the area you wish to zoom to in the lower left of the spectrogram. The screen should now look like something like Fig. A7.7.

4. You can now zoom in to your selection by clicking on the button marked by the green circle in Fig. A7.7, to give you something that looks like the screenshot in Fig. A7.8 (which looks horrific!). If you are not happy with your selection, you can reverse it by clicking on the 'expand' button, which is found to the right of the zoom button (see Fig. A7.9), and try again.



☐ Waveform 1
☑ Spectrogram 1

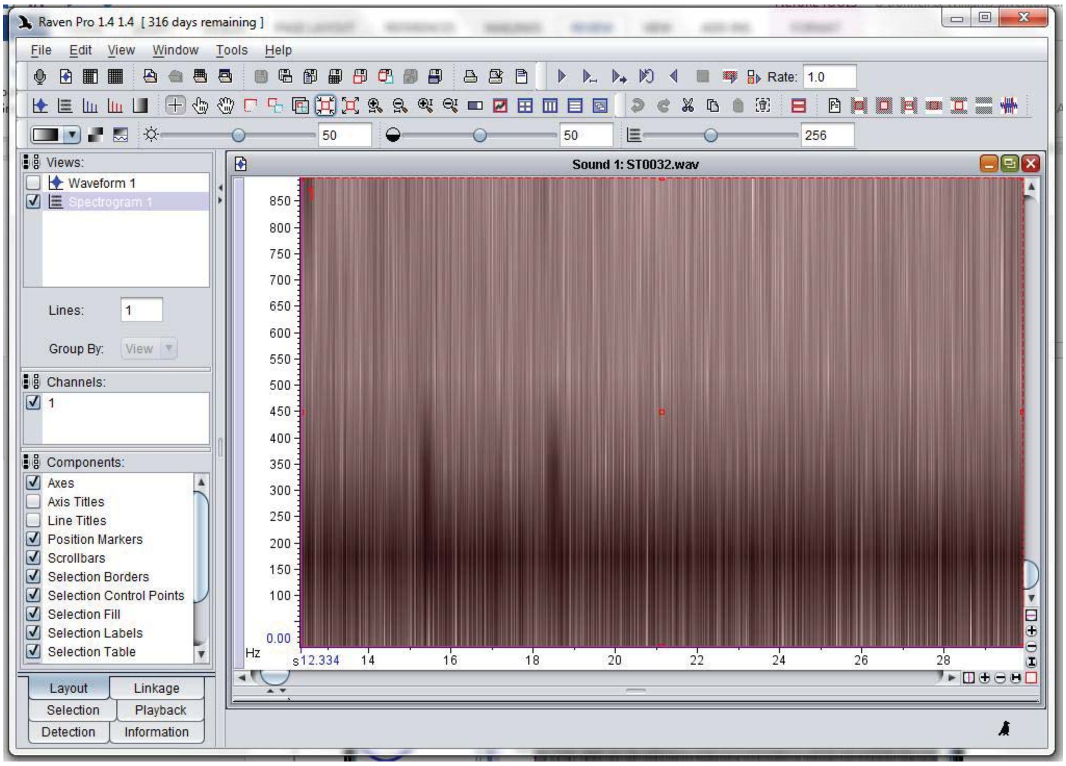
Lines: 1

Group By: View

☑ 1

☑ Axes
☐ Axis Titles
☐ Line Titles
☑ Position Markers
☑ Scrollbars
☑ Selection Borders
☑ Selection Control Points
☑ Selection Fill
☑ Selection Labels
☑ Selection Table
☐ Measurements
☑ View Selection Buttons
☐ Major Grid

Figure A7.7. Drawing a box over the area you wish to zoom to in the lower left of the spectrogram.



☐ Waveform 1
☑ Spectrogram 1

Lines: 1

Group By: View

Channels:
☑ 1

Components:
☑ Axes
☐ Axis Titles
☐ Line Titles
☑ Position Markers
☑ Scrollbars
☑ Selection Borders
☑ Selection Control Points
☑ Selection Fill
☑ Selection Labels
☑ Selection Table

Figure A7.8. Zooming into an area of interest before sharpening the image.

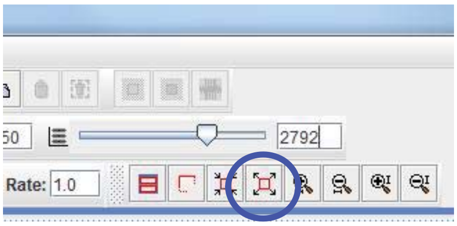


Figure A7.9. Showing the expand button (circled in blue).

5. Once you have zoomed to an area that you are happy with you will need to alter the sharpness (see Fig. A7.10). A value of around 2792 is recommended.

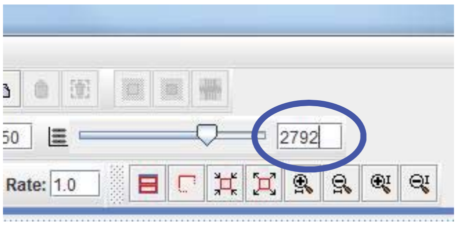
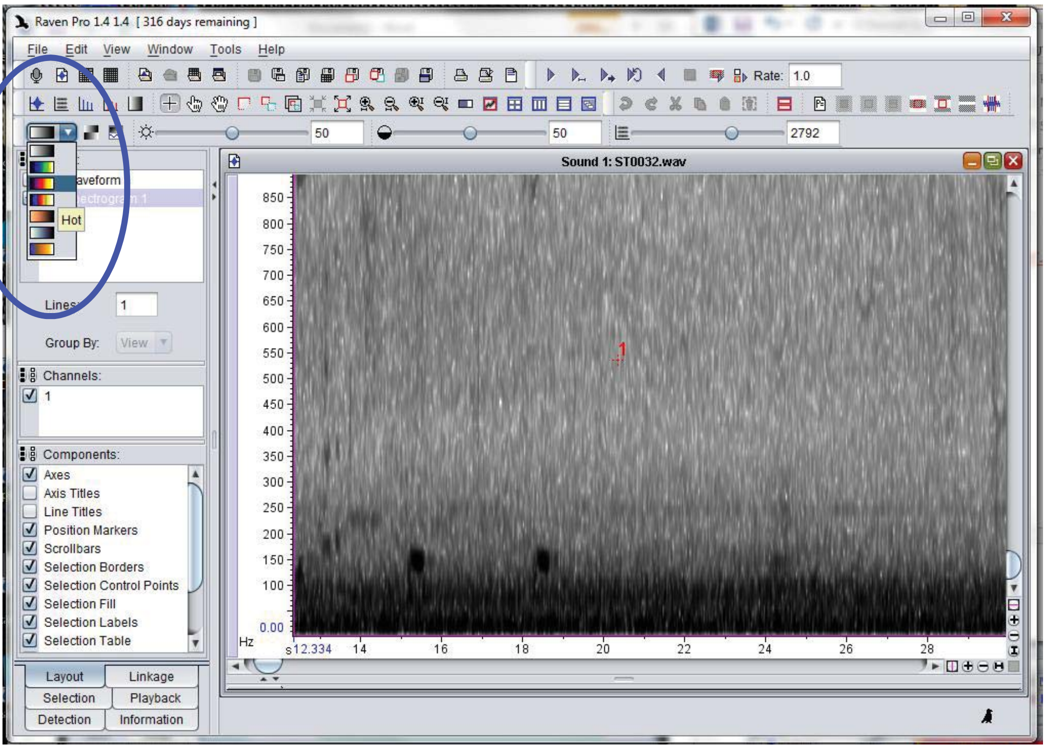


Figure A7.10. Alter the sharpness to a value of around 2792.

6. Next change the colour of the spectrogram using the colour map drop box (circled in blue on Fig. A7.11). The option ‘hot’ is useful for seeing

bitterns, but the choice is really personal preference. Now your screen should look like Fig. A7.12.



Rate: 1.0

50

50

2792

Lines: 1

Group By: View

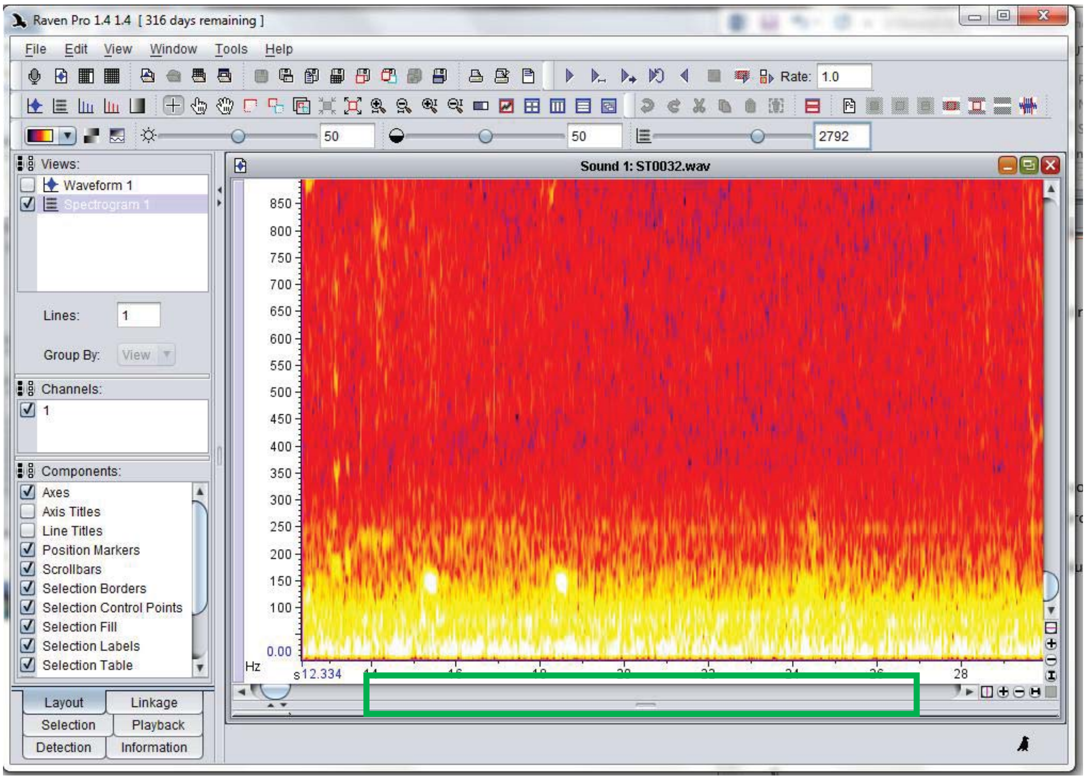
Channels:

☑ 1

Components:

☑ Axes
☐ Axis Titles
☐ Line Titles
☑ Position Markers
☑ Scrollbars
☑ Selection Borders
☑ Selection Control Points
☑ Selection Fill
☑ Selection Labels
☑ Selection Table

Figure A7.11. View after zooming in to the selection. The colour map drop box, where you can change the colour of the spectrograph, is circled in blue. The option 'hot' (3rd down) is recommended for seeing bittern booms.



Rate: 1.0

50

50

2792

Views:
☐ Waveform 1
☑ Spectrogram 1

Lines: 1

Group By: View

Channels:
☑ 1

Components:
☑ Axes
☐ Axis Titles
☐ Line Titles
☑ Position Markers
☑ Scrollbars
☑ Selection Borders
☑ Selection Control Points
☑ Selection Fill
☑ Selection Labels
☑ Selection Table

Figure A7.12. View after changing colour to 'hot'.

7. The bittern boom sequences should now be visible (circled in blue in Fig. A7.13). Note: There are three booms within this single sequence; the last two are quite obvious, but if you look closely and listen with good quality headphones you will discover that there is also a poor boom at the beginning of the sequence (shown by the blue arrow).

8. Scroll through the file looking for any bittern calls. To do this, left click anywhere on the scroll bar (area marked with a green square in Fig. A7.12). This will move your screen along at a rate of 15 seconds per click.

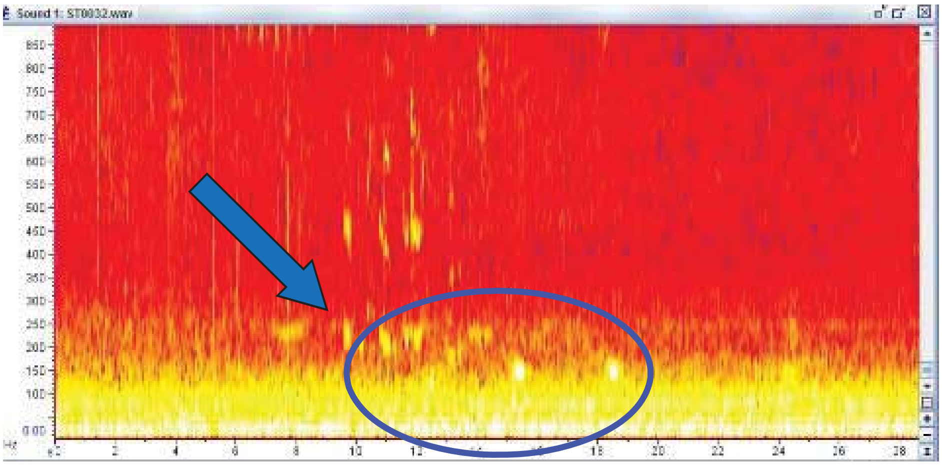


Figure A7.13. Bittern booms become visible after changing the sharpness of the view to 2792.

A7.4 Detecting bittern booms

You are looking for a series of small yellow/white signatures sitting at around the 150-Hz mark. Once you have found a suspect signature at this frequency, you should look at the following:

- **If more than one signature is present, do they appear in a pattern, with each signature roughly spaced at regular intervals?** If so, the call is likely to be a bittern and worth further investigation. However, do not expect interval distances to be perfectly uniform. Occasionally, odd booms within a sequence will appear to be missing or only have a faint trace, so be aware that there can be a lot of variability. The distance between bittern booms is usually about 1–3 seconds, but can be up to 10 seconds, particularly early in the booming season.

- **Are there any other patterns above the suspect signature?** Bittern calls do not leave any imprints at frequencies higher than 200 Hz, so if patterns are appearing above the suspect signature then it is either not a bittern or something has produced a noise at the same time as the bittern.

You may need to listen to the sound file to confirm that what you are seeing is definitely a bittern boom, particularly when you are starting out. If in doubt, you are welcome to take a screenshot or cut that section of the call and send it to Emma Williams (bittern.wills@yahoo.com) for a second opinion. Note: It is not uncommon for bitterns to produce single booms, or for one or more of the booms in a sequence to be less well defined.

Figure A5.14 shows several sample boom sequences that illustrate some of the variability you may encounter:

A. One boom sequence containing three ‘good’, well-defined booms.

B. One boom sequence containing three booms. Inhalations are visible around the 200-Hz mark in this example.

C. One boom sequence containing three booms. This is much earlier in the booming season when the booms from some individuals are fainter and less well defined.

D. One boom sequence containing two booms. If you look carefully, the inhalations are visible. Again, this is a recording taken much earlier in the season when the booms of some males sound more ‘cough-like’.

E. One sequence containing two booms that are barely visible because of faint train noises in the background. This example highlights the importance of careful placement of units.

F. One sequence containing four booms that are barely visible because of high background noise (wind).

G. One sequence that contains at least three (but possibly four) booms. This sequence is also barely visible because of high background noise (wind).

Figure A7.15 shows some typical background noises:

H. Light wind can hide a bittern boom.

I. Cows can leave signatures at a similar frequency to bitterns but, unlike bittern signatures, will continue up at higher frequencies. Pūkeko (*Porphyrio porphyrio melanatus*) also make some calls that show as signatures around 200 Hz, which is why **it is important to check for any imprints up to 800 Hz**—if similar signatures appear at higher frequencies, it is very unlikely to be a bittern.

J. Swans can leave vocal signatures at a similar frequency to bitterns but, unlike bittern signatures, these calls are slightly lower in frequency and the signature often repeats at higher frequencies (approximately 300–350 Hz).

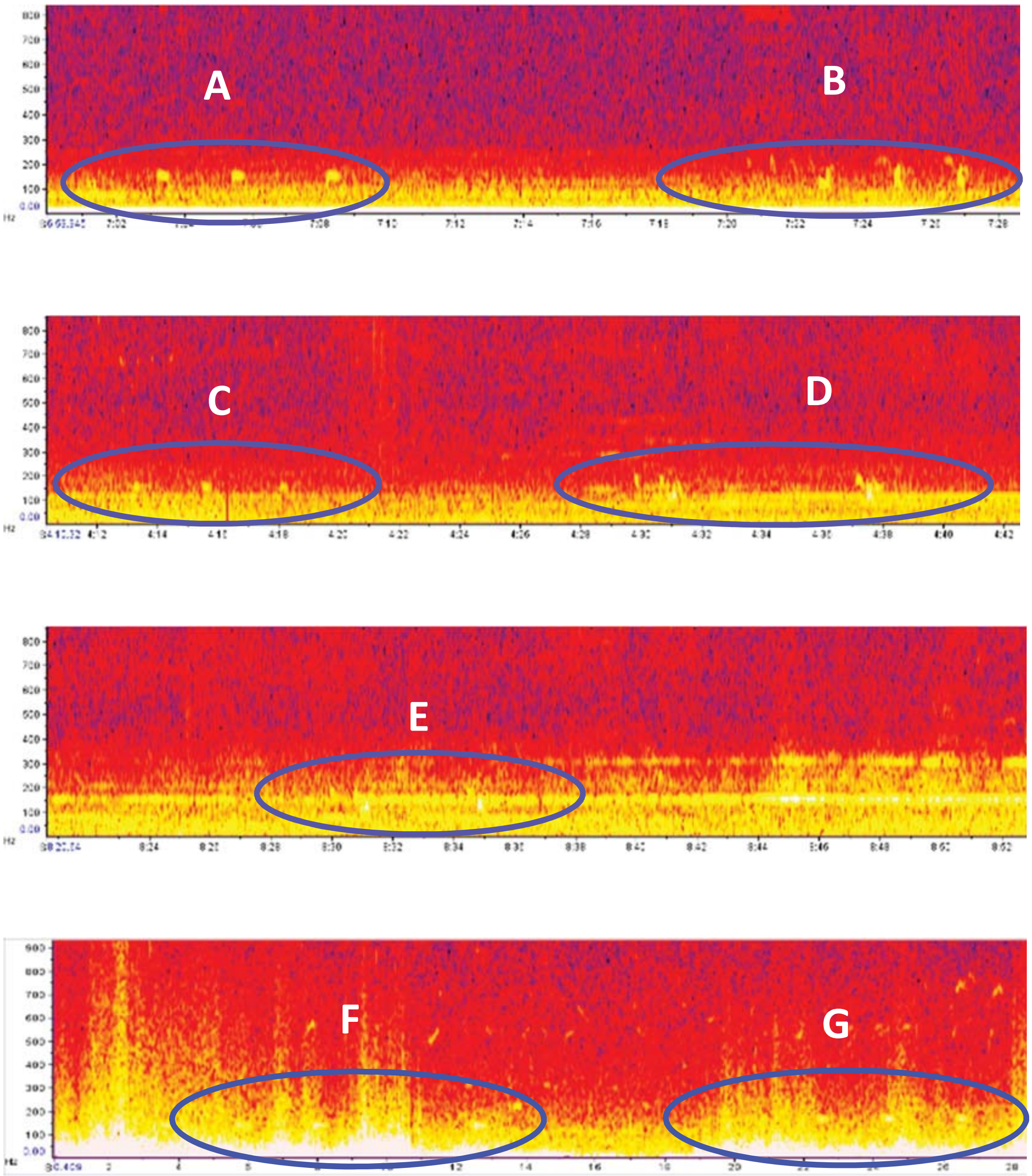


Figure A7.14. Examples of bittern boom sequences, showing the level of variation (see text for detail).

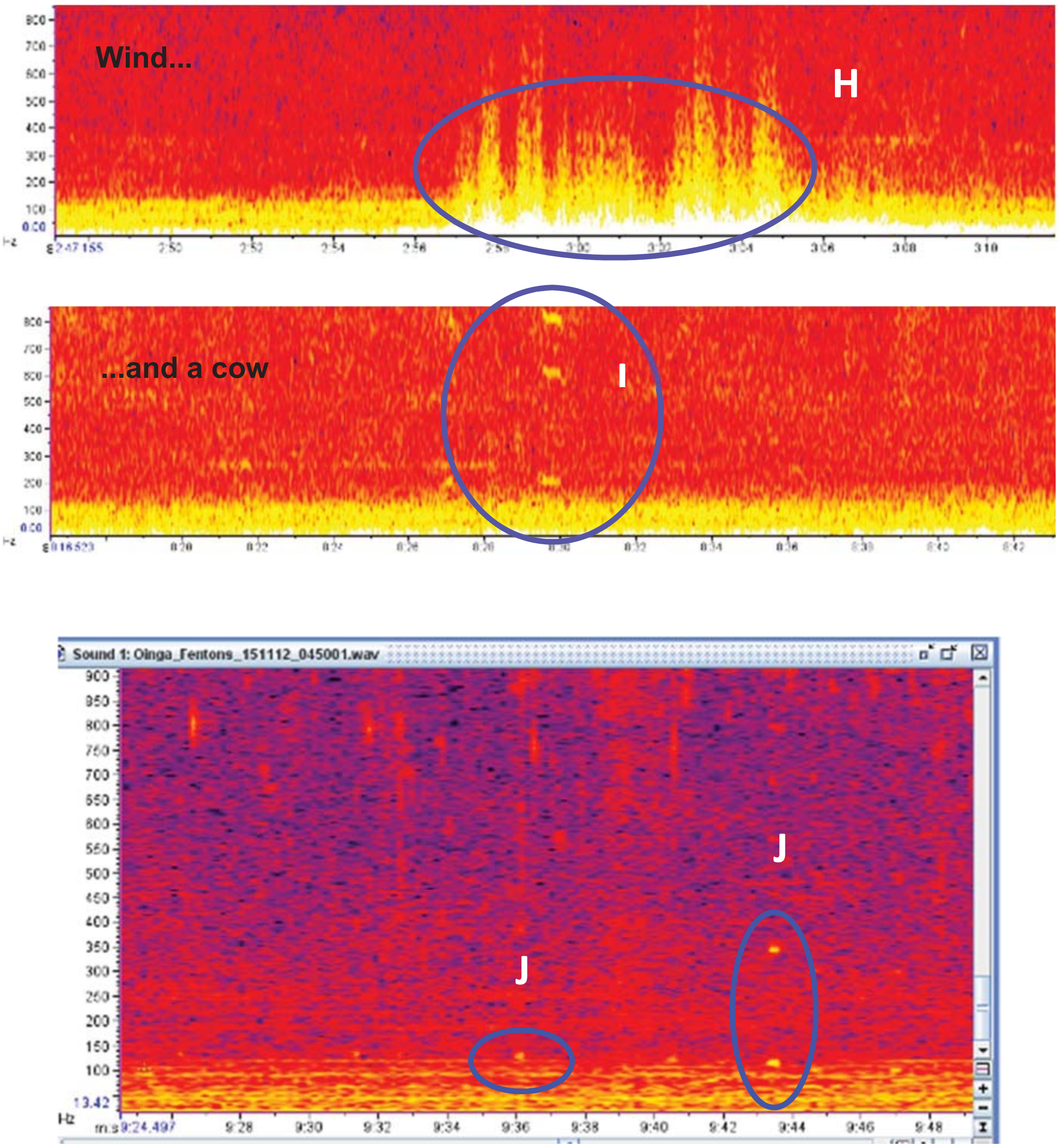


Figure A7.15. Disturbances that affect the ability to detect bitterns (see text for detail).

A7.5 Listening to files to confirm booms

Listening to files can help to confirm a boom that is suspect. To do this, click on the window somewhere just before the suspect boom and play the file using the play button (circled in Fig. A7.16).

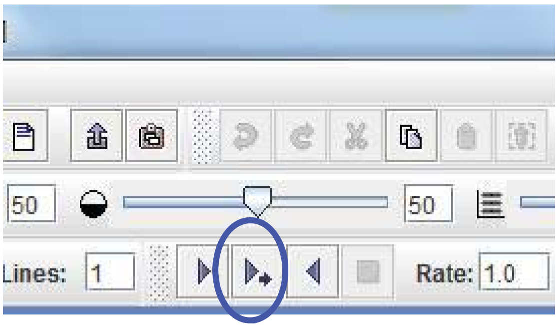


Figure A7.16. Play button.

To hear bittern calls, you may need to invest in a pair of headphones that are of reasonable quality. Cheap headphones often do not cope well with lower frequency calls such as bittern calls. We use Sennheiser headphones (HD 201 or HD 202), which can be purchased from most electronic stores and cost approximately NZ$80. If in doubt, an example soundfile is available from Emma Williams (bittern.wills@yahoo.com) that allows you to test whether you can hear the bittern calls with your headphones.

A7.6 Creating window presets (RavenPro only)

Once you are happy with your settings, you may wish to save them so that you can go straight to the optimal settings to see bittern calls as soon as each file is loaded.

To do this:

1. Make sure all of your settings are correct (see section A7.3).
2. Save your settings by clicking on View > Window Preset > Save As… (see Fig. A7.17).
3. Choose a suitable name for your preset (in this case ‘Bittern’ is appropriate).
4. Now every time you open a file select View > Window Preset > Bittern and your window will zoom automatically to the optimum settings to view bittern booms.

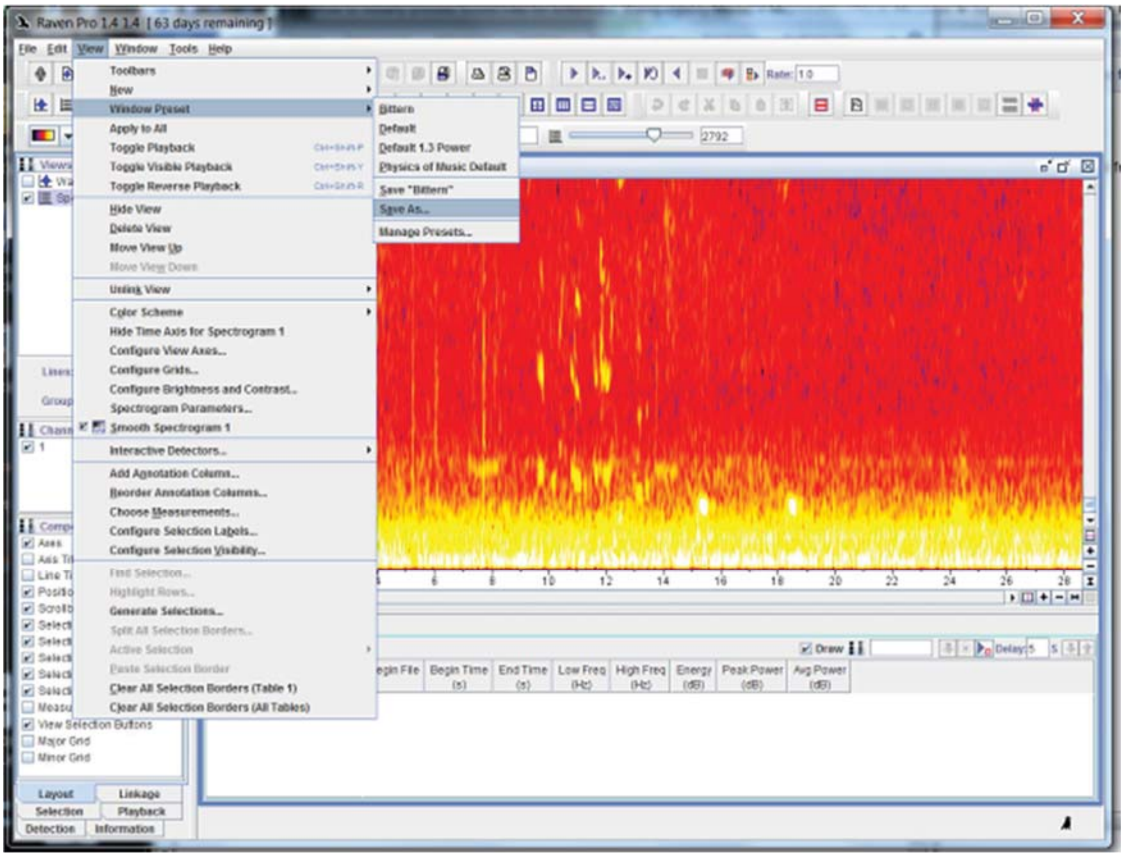
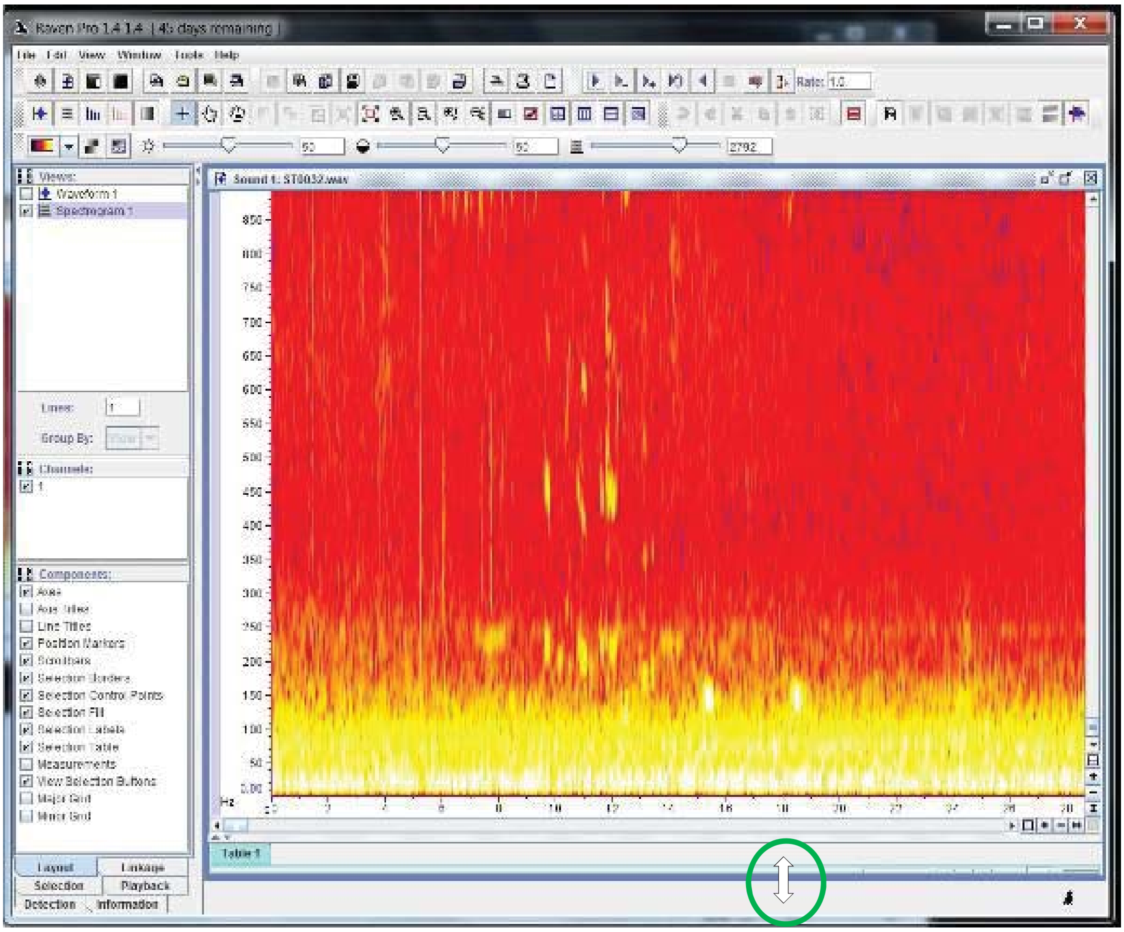


Figure A7.17. Creating preset window settings.

A7.7 Selecting additional attributes to be measured (RavenPro only)

Depending upon your aims and objectives, you may wish to measure some additional attributes for each call found. These can be found below your spectrogram under the tab ‘Table 1’:

1. First expand your view so that you can see the full table. To do this, left click on the area shown in the green circle on Fig. A7.18 (note: when you do this, your cursor should change to a double-headed arrow as shown in the figure).
2. While holding your left mouse button down, drag the window upwards until you can see the full table.
3. You will now see that your table already has some headers, e.g. ‘Selection’, ‘View’ and ‘Channel’. If you right click on any of these headers you will get a drop-down list (Fig. A7.19). Go to ‘Choose Measurements’ from this list.
4. Now you can move any measurements that you are interested in into the left-hand box (see large blue circle on Fig. A7.20) using the double arrows (small circle on Fig. A7.20).



Views:
☐ Waveform 1
☑ Spectrogram 1

Lines: 1
Group By:

Channels:
☑ 1

Components:
☑ Axes
☐ Axis Titles
☐ Line Titles
☑ Position Markers
☑ Scrollbars
☑ Selection Borders
☑ Selection Control Points
☑ Selection Fill
☑ Selection Labels
☑ Selection Table
☐ Measurements
☑ View Selection Buttons
☐ Major Grid
☐ Minor Grid

Figure A7.18. Expand the ‘Table 1’ tab by holding your mouse button down and dragging the bar upwards until the whole table is visible.

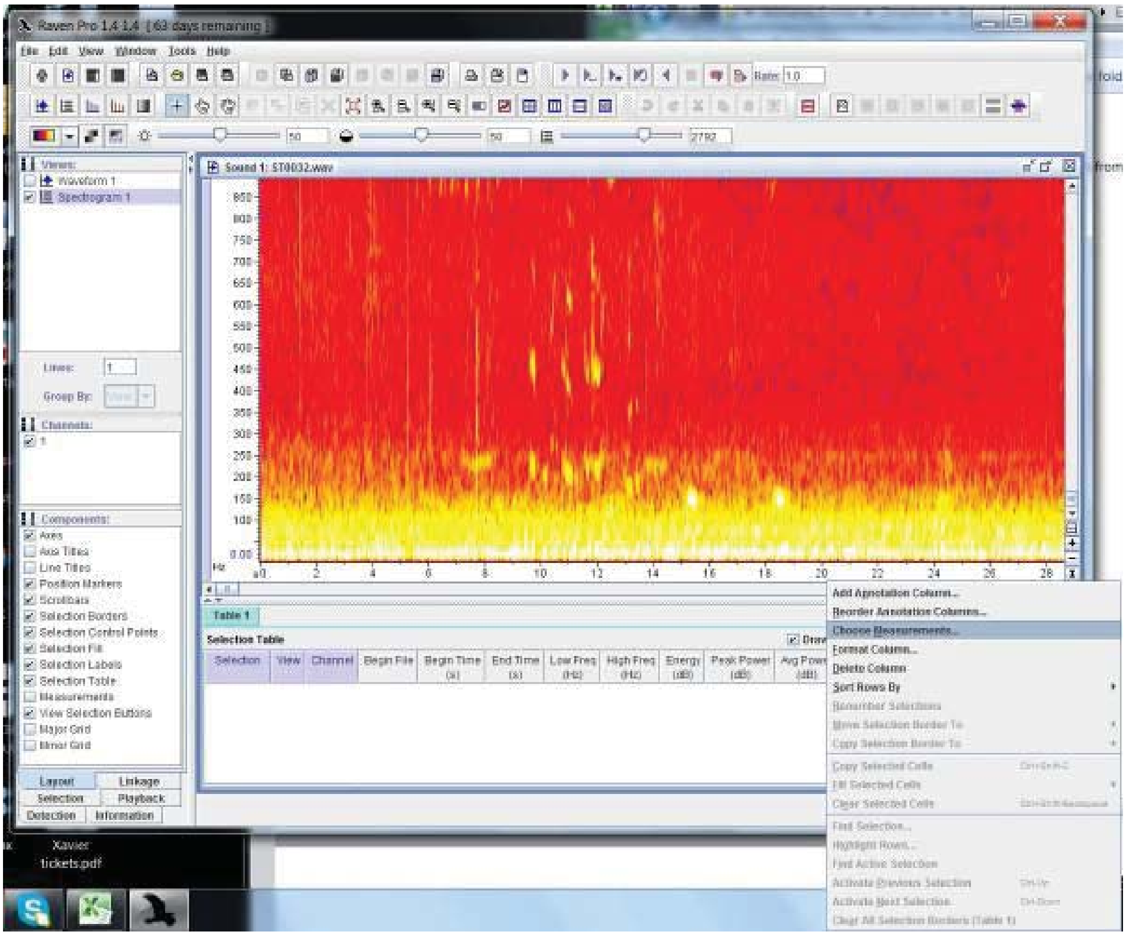


Figure A7.19. Drop-down list showing 'Choose Measurements' option.

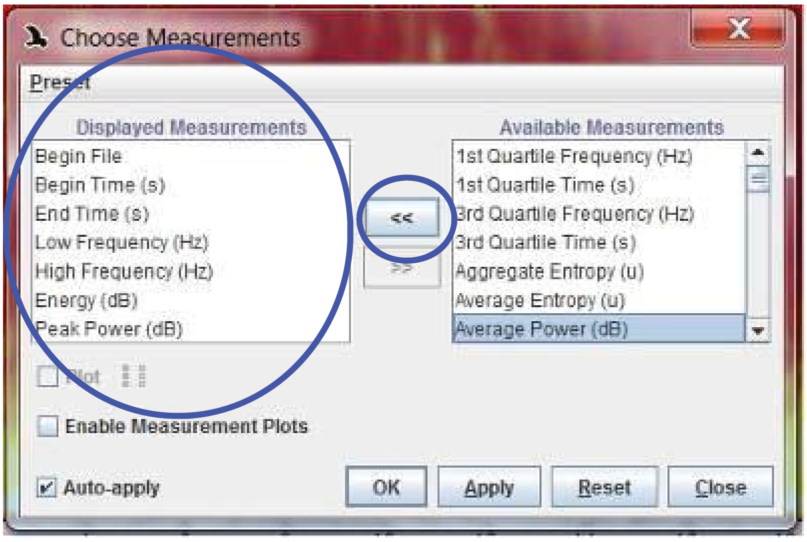


Figure A7.20. Choosing your measurements.

The following measurements are recommended:

Begin File—Contains the file name

Begin Time (s)—The number of seconds into the file where the boom starts

End Time (s)—The number of seconds into the file where the boom finishes

Low Freq (Hz)—Defines the bottom edge of the box you created

High Freq (Hz)—Defines the top edge of the box you created

Energy (dB)—The total energy within your defined area

Peak Power (dB)—The maximum power within the defined area; when using the colour ‘Hot’, this will be the power reading at the lightest point in the defined area

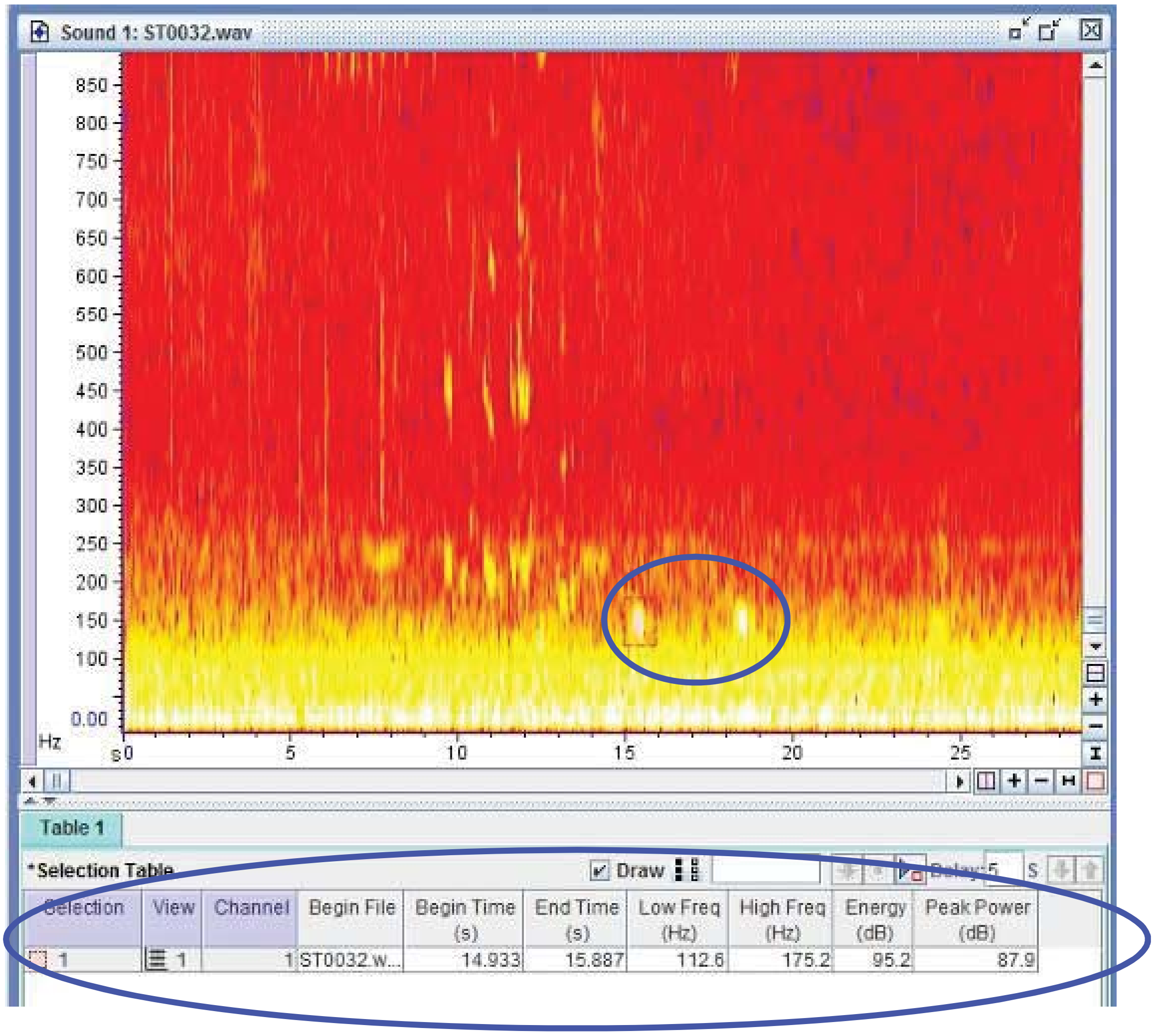
Avg Power (dB)—Measures the power per pixel and averages this across all pixels in the selection

You can change the order of your list by clicking and dragging attributes into the order that you would prefer. Reorder this list so that they are the same order as the spreadsheet that you are storing you data in.

Once you are happy with the list and its order, click on ‘Apply’. Now you are ready to take your measurements. If you have already created a preset window called ‘Bittern’, you should resave it with these settings by clicking on View > Window Preset > Save ‘Bittern’.

A7.9 Measuring additional attributes of the call (RavenPro only)

To measure these additional attributes, first draw a box around the area you wish to assess—in this case, a single bittern boom. Take care to keep your box as small as possible so that you only include the specific sound you are interested in. Measurements for each of the attributes of this call will now appear automatically in the selection table at the bottom of your screen (Fig. A7.21).



Selection	View	Channel	Begin File	Begin Time (s)	End Time (s)	Low Freq (Hz)	High Freq (Hz)	Energy (dB)	Peak Power (dB)
1	1	1	ST0032.w...	14.933	15.887	112.6	175.2	95.2	87.9

Figure A7.21. Showing additional attributes of the call in RavenPro 1.4.

You can copy and paste these into another program, e.g. Microsoft Excel. To do this, highlight the cells by clicking on them, then right click and go to ‘Copy Selected Cells’ (Fig. A7.22). Now they can be pasted wherever you would like them to go, e.g. in the relevant cells of Excel. Note: Holding down ‘Ctrl’ and ‘C’ does not work in Raven.

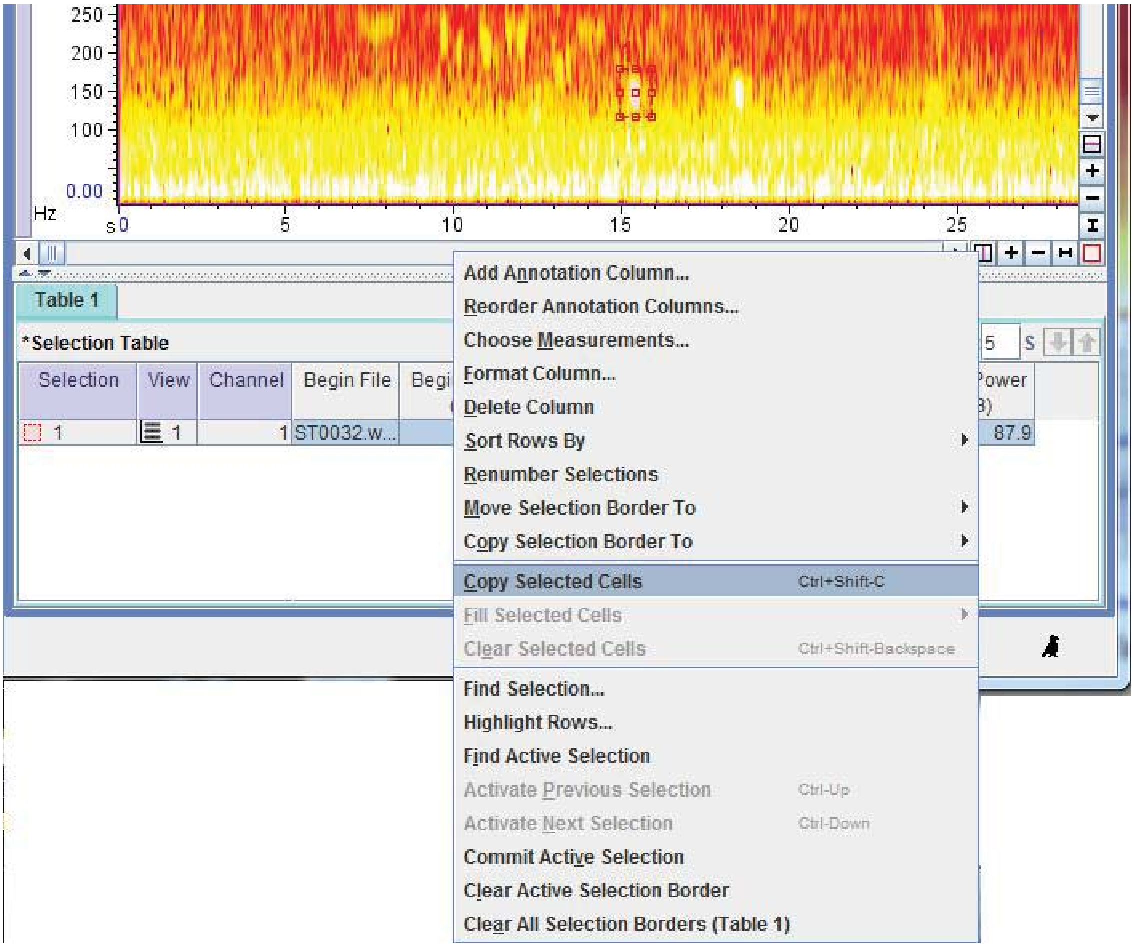


Figure A7.22. Copying the call attributes for use in another program.

A7.8 Processing your sound files and entering your data

Each time you want to process a sound file you just have to complete the following steps:

1. Load the file (see section A7.3—'Opening sound files' if you need a reminder of how to do this).

2. Zoom to the relevant preset view (see section A7.6) by clicking on View > Window Preset > Bittern (if applicable).

3. Scroll through the file looking for any suspect calls by clicking on the scroll bar to move the screen forward by 15 seconds with each click (see area marked with a green square in Fig. A7.12):

    - If you find a call (or a suspect call), first have a listen (see section A7.6—'Listening to files to confirm booms'). If you are not sure whether or not it is a bittern, you are welcome to send screenshots and sound files to Emma Williams at bittern.wills@yahoo.com for a second opinion. If it is a bittern, draw a box around each boom, then copy and paste the attributes that appear in the bottom of your screen into Excel as you go (see section A7.9—'Measuring additional attributes of the call (RavenPro only)'). Note that 'Ctrl' and 'C' does not work in Raven. Add your initials under Processor, 'Bittern' in the species column, and number the booms (Boom#) and call sequence (Call#) accordingly; for example, if it is the second boom of the first call sequence to be found in that file, put one in the ‘Call#’ column and two in the ‘Boom#’ column. So if, for example, you found five booms in the first call sequence of a file, you would expect to input five rows of data numbered 1–5 under the column ‘Boom#’, each of which would be labelled with a 1 under the column ‘Call#’; if you then found that the second call sequence on the same file had two booms, you would expect to enter two rows of data numbered 1–2 under ‘Boom#’, each labelled with a 2 under ‘Call#’.

- If no calls are found in a file, enter the file name in a row of your Excel spreadsheet, add your name as a processor and put ‘NONE’ in the column species. Now you are ready to start the next file.

Appendix 8

Power to detect a decline in the calling-rate of the Australasian bittern at Whangamarino wetland.[5]

A8.1 Introduction

To adequately monitor Australasian bitterns, a method is required that has the ability to detect a certain level of population change with a certain confidence but also has a low risk of falsely detecting a trend. This ability to detect a level of change is influenced by the duration of monitoring (number of years), the number of samples collected (number of stations), the frequency of repeats and the amount of variability in calling-rates. The influence each of these factors has on the ability to detect a change can be statistically measured using power analysis (Murphy, 2014)[6].

A8.2 Aim

The aim of this sections is to investigate: 1) the level of population change that can be detected in 5 year and 10 year timeframes at Whangamarino wetland with a call-count monitoring method (outlined in Chapter 4); 2) to use data from a pilot study conducted in 2009 and 2010 to make recommendation regarding the number of stations and frequency of repeats to monitor Australasian bitterns at Whangamarino wetland.

A8.3 Methods

Study Area

Call count surveys were conducted in Whangamarino wetland (175°07'E, 37°18'S), in the Waikato region, New Zealand. This bog/swamp complex is situated 4.2 m above sea level, approximately half-way between Hamilton and Auckland; and covers 7290 ha, making it the second largest wetland in the North Island of New Zealand (Figure 3.1, Chapter 3).

Call count surveys

Observers listened and noted all Australasian bittern calls heard from fixed locations during surveys lasting 15 min (Chapter 4). These surveys were conducted in 2009 and 2010 between 10th September and 30th November, a period that corresponds with the bittern breeding season (O Donnell, 2011). In 2009, 86 fixed points (or stations) were surveyed (see map). These stations were positioned ≥400 m apart in easily accessible areas of the wetland. All 15 min counts were conducted within one of two daily observation periods that represent peak booming activity, each spanning five hours (03:00-08:00 including sunrise and 17:30-22:30 incorporating sunset). In 2010, 40 of these stations were repeated using the same sampling regime.

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[5] This section is all my own work and was originally intended to be the main focus of a chapter in the thesis. This work was surpassed in favour of Chapter 5 but is included here to support Chapter 4.

[6] Murphy, K. R. (2014). Statistical power analysis a simple and general model for traditional and modern hypothesis tests (4th ed.). Hoboken, United States: Taylor & Francis

Overall, the 80 survey locations were chosen to represent the best coverage of the wetland possible and therefore represented a mixture of areas of high and low bittern activity. The vastness of Whangamarino wetland makes it impractical to spatially randomise the sampling of all stations. Instead, stations were randomised to determine the first station to be surveyed for each survey period. Thereafter, all subsequent surveys for that period were conducted at stations in close proximity to the starting station.

Power Analysis

The power to detect a linear trend in bittern calling-rates between seasons was simulated using the software Monitor 11.0.2 beta. This program generates power estimates using a simple linear Monte Carlo model that is assumed to be log-normally distributed.

Initial plot values of 10.08 and 7.85 calls per 15 min period were used for morning and evening surveys, with total variations of 10.21 and 8.71 respectively. These plot values represented the mean calling-rate calculated across all stations and years within the wetland. Total variation values represent the standard deviation of the mean and were assumed to be constant across time.

Values for the number of plots and intervals were then manipulated to allow direct comparisons of power estimates for each combination of station number (1-80) and year (1-10).

A8.3 Results

Number of years and number of stations

As expected, the higher the number of stations sampled, the greater the power to detect a trend. Overall, the power to detect an increase in bittern calling rates was higher compared with the power to detect a decline. Monitoring could detect a change of <10% in bittern calling-rate with 90% power over 5 years using <80 stations. However, even after 10 years of monitoring it was not possible to show a change in calling-rate of <2% with 80 stations (Fig. A8.1).

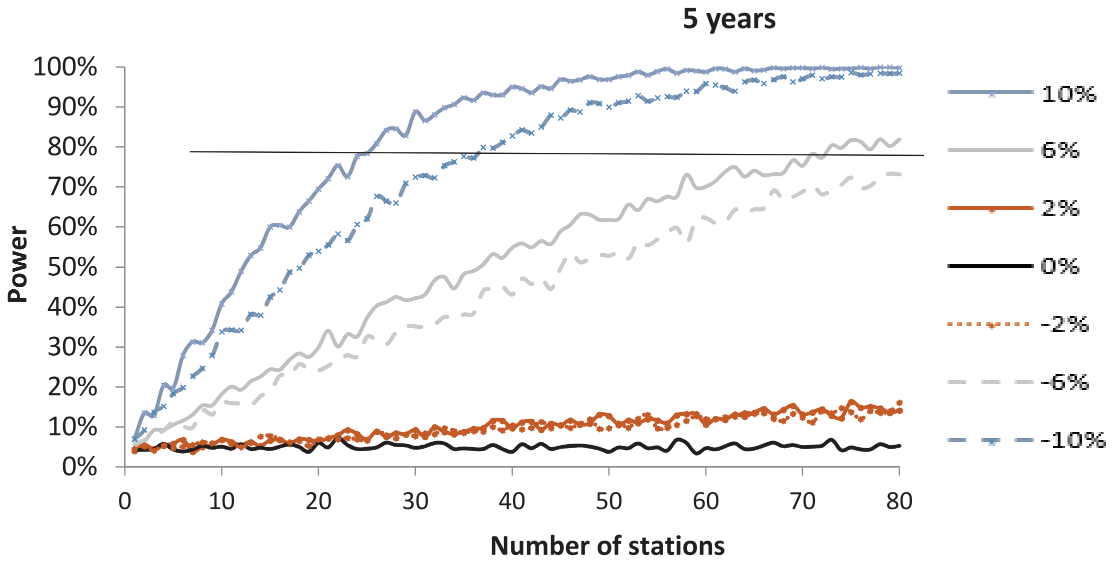

Figure A8.1: Power to detect a change in the number of Australasian bittern calls over 5 years.

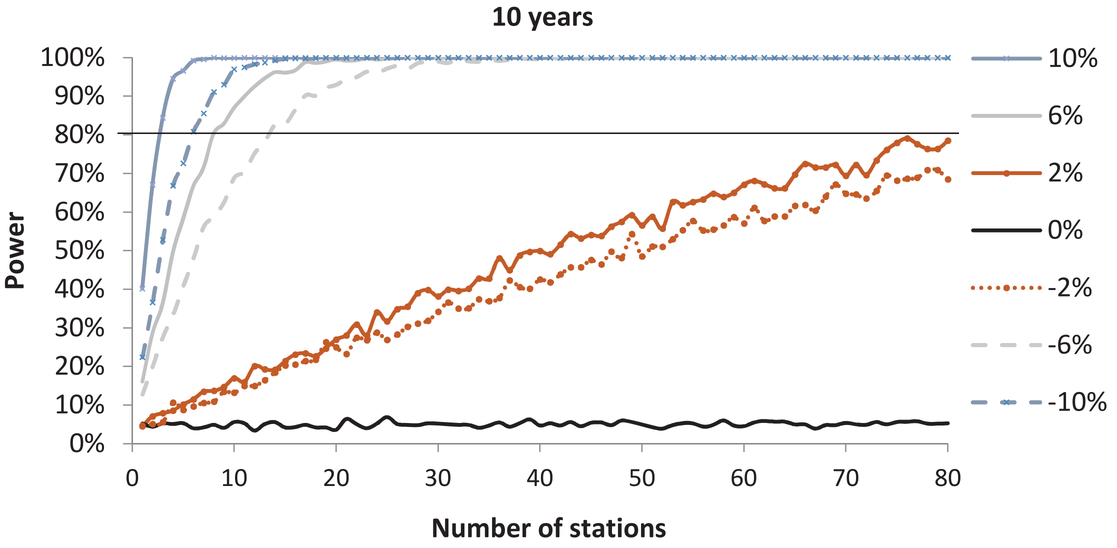

Figure A8.2: Power to detect a change in the number of Australasian bittern calls over 10 years.

Morning surveys versus evening surveys

Conducting monitoring during optimum morning periods, rather than evening periods, increased the power to detect a 5% decline in calling-rate over 80 stations by 10% over <5 years. However, as the number of years monitored increased this difference becomes less apparent, and negligible if monitoring continues for > 10 years (Figure A8.3)

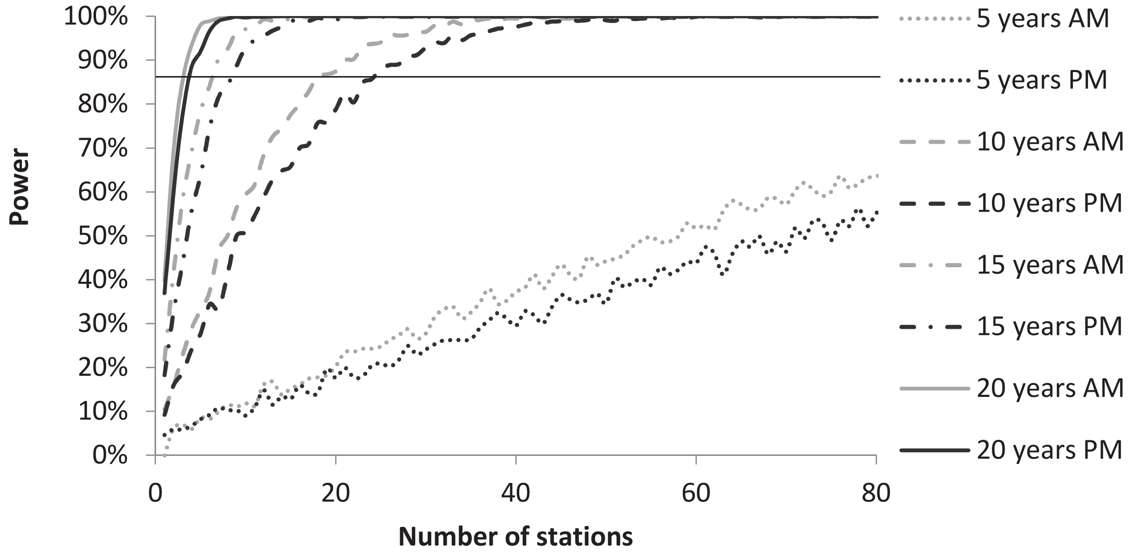

Figure A8.3. A comparison of the power to detect a 5% decline in the number of calls produced by Australasian bitterns using a call count method at Whangmarino wetland. Calls counts were conducted during the Australasian bittern breeding season in 2009 and 2010. AM represents surveys conducted in the morning, while PM represents surveys conducted in the evening (see text).

Appendix 9

Table A9.1: Details of six male bitterns captured at Lake Whatumā using cage traps, August to November, 2014.

Date Captured	Bird Name	Tx	Fixes	Band	Weight (Kgs)
29/08/2014	Barry White	08	79	M91420	2.03
09/09/2014	Bing Crosby	02	28	M73997	1.98
14/10/2014	Tama Tomoana	16	42	M73998	1.86
23/10/2014	Howard Morrison	10	27	M73999	1.86
10/11/2014	Prince Tui Teka	20	20	M91417	1.83
10/11/2014	Elvis Presley	12	12	M91418	1.73

Appendix 10

Locations of animals hidden in images

Chapter 1

Chapter 5

Chapter 6

Chapter 7