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Strategic principles and tactical options for managing wild deer in Northland Region

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Summary

Project and Client

- Northland Region is currently reviewing its wild deer management plan. The following report aims to assist with this process by summarising strategic principles for managing wild deer, providing expert opinion about what new control and surveillance methods might be useful for wild deer management in Northland, and suggesting priorities for testing. It was completed by Landcare Research, Lincoln, for Northland Regional Council during October 2015 and January 2016.

Background and Objectives

- Although wild deer management over the past c. 18 years has failed to keep Northland Region free of wild deer, it has successfully eliminated some isolated populations of wild deer and kept others at exceedingly low numbers. The primary constraints to complete removal of wild deer in the region are deer escapes from farms and illegal releases of wild deer.
- The objectives of this report include:
    - Set out the general best practice strategies for controlling or eradicating deer and place Northland's historical and current management efforts within this theoretical framework.
    - Review new control and surveillance methods for wild deer management in Northland, and suggest priorities for testing.
    - Identify key knowledge gaps that may help to improve wild deer management in Northland.

Results

- Regional scale eradication is unlikely to be successful unless sources of reinvasion can be adequately managed. The greatest risks include deer escapes from farms and illegal liberations. Natural dispersal from northern Auckland Region to southern Northland Region is also a potential source of reinvasion; however, given the current low densities of deer in northern Auckland Region, excluding the South Kaipara fallow deer herd, this is considered a comparatively low risk factor.
- Resources will probably be inadequate for management agencies to formally monitor the greater Northland Region to detect new incursions. A more effective approach is to maintain and enhance the early reporting system (Find Deer Hotline) to maximise information from the public and continue to build positive relationships with farmers to improve deer husbandry, particularly fencing, and effective management of any escapes that do occur. Together with information originating from management agencies and the professional deer response team, stratified surveillance and monitoring programmes can then be targeted to areas where they are likely to enhance management.
- Lethal control methods – ground- and aerial-based hunting – are most suitable for wild deer management in Northland and should be used to eliminate herds of wild deer that

meet the obligate rules necessary for eradication and keep other herds at the lowest achievable densities. Non-lethal control methods are likely to be too expensive for use on the exceedingly low numbers of deer found in the region and ineffectual in the logistically challenging terrain where most wild deer occur.

- New or improved technologies are being increasingly included into surveillance and control programmes. These are discussed and priorities for testing are suggested.

Recommendations

- Although eradication of wild deer from Northland at a regional scale is unlikely to be achieved unless issues related to escapes from deer farms and land access for professional hunters are resolved, populations that meet the requirements for eradication should be targeted for elimination. For all other populations, the management objective should be the lowest achievable density.
- The early reporting system (Find Deer Hotline – 0800 346 333) should continue to be used to gather information from the public about sightings of wild deer or escaped farm deer. The Northland deer response team should continue to prioritise informal farm visits to obtain/maintain buy-in from deer farmers, and help improve deer husbandry and manage deer escapes.
- The use of professional fulltime ground hunters (using trained dogs, as required) should continue to be the primary method of removing wild deer and escaped farm deer (unless recaptured) from Northland Region. A succession plan should be established to ensure future capability as the current deer response team nears retirement age. Some combination of performance-based contract and hourly rate might be most appropriate for professional hunter services.
- Northland's professional deer response team should consider using aerial shooting of wild deer from a helicopter where there is suitable habitat, particularly pasture–forest margins, scrub, and native and plantation forests with canopy that is sufficiently open to allow deer to be seen and shot.
- The use of thermal infrared imaging technology should continue to be incorporated into deer management in the region. This may include both ground- and aerial-based use of equipment and will have application for both surveillance and control.
- The strategic use of camera traps, acoustic monitoring devices, and Judas deer will provide fine-scale data about seasonal habitat use, movement corridors, and confirming group sizes and sexes, and thus may assist the response team to increase their kill rates by improving their knowledge about when and where to target deer.
- If a performance-based contract model is adopted for professional hunters, a protocol will need to be developed to independently evaluate whether or not a defined outcome has been achieved.
- If new control strategies and methods are adopted, it may be necessary to refine data collection, management, and analysis processes. The above successional plan should ensure that future capability includes rigorous training in data collection and management by professional hunters, as well as appropriate institutional data management and analysis.

1 Introduction

A small number of wild deer populations became established in Northland Region in the late-1980s and attempts to remove these populations are ongoing. Landcare Research, Lincoln, was commissioned by Northland Regional Council to contribute to a review of their wild deer management plan. In particular, Landcare Research was asked to summarise strategic principles for managing wild deer in the region, provide expert opinion about what new control and surveillance methods might be useful for wild deer management in Northland, and suggest priorities for testing. The review was conducted between October 2015 and January 2016.

2 Background and Objectives

The management of wild deer in Northland Region – both existing low density populations and new incursions – needs to be based on best practice strategies and appropriate control solutions. To date, management has aimed to keep the region free of wild deer (McKenzie et al. 2004). This has been done through a combination of eliminating (or attempting to eliminate) established populations of wild deer, minimising escapes from deer farms by improving livestock husbandry, and using an early reporting system to quickly manage any farmed deer that do escape (Fraser et al. 2003; Gardiner 2015). Although management efforts over the past c. 18 years have failed to keep Northland free of wild deer, they have successfully eliminated some isolated populations of wild deer (i.e. at a site scale as opposed to a regional scale; Fraser et al. 2003) and have been very effective at keeping wild deer at exceedingly low numbers elsewhere in the region. Ongoing monitoring/surveillance, followed by prompt control responses, within the region have ensured that the situation has not worsened.

The objectives of this report include:

1. Set out the general best practice strategies for controlling or eradicating deer and place Northland's historical and current management efforts within this theoretical framework

2. Review new control and surveillance methods for wild deer management in Northland, and suggest priorities for testing

3. Identify key knowledge gaps that may help to improve wild deer management in Northland.

The information in this report may identify where improvements can be made in future surveillance and control or eradication attempts; however, equally importantly, it will help to determine what is and what is not achievable in terms of wild deer management in Northland and to revise Northland's wild deer plan accordingly.

3 Results

3.1 Strategic principles for managing wild deer

Options for managing wild deer in Northland include ‘do nothing’, ‘prevent establishment’, some form of ongoing ‘sustained control’, or ‘eradication’. Because wild deer numbers in Northland are currently at very low densities and because they could have significant unwanted impacts if allowed to increase in numbers and distribution (Sweetapple 2006), I follow the precautionary objectives of Northland Region’s current wild deer management plan (McKenzie et al. 2004) and accept that doing nothing is not an option. Preventing establishment can be done in various ways. I do not discuss options such as fencing high value assets to prevent deer incursions, although this might be an option for some areas, particularly if wild deer were to become common and widespread in Northland. In situations where preventing establishment involves removing deer that have recently invaded an area (either by an illegal liberation, farm escape or natural dispersal), these are included in discussions relating to control to low density and eradication.

3.1.1 Key requirements for eradication

Obligate rules

Keeping Northland free of wild deer clearly implies that management over the past c. 18 years has been targeted at eradication. However, eradication requires a number of conditions be met before it is intrinsically feasible, as well as a set of constraints that need to be managed before a project is started. Six strategic rules are used to judge whether eradication is feasible (e.g. Bomford & O’Brien 1995; Parkes & Panetta 2009). Briefly these are: (1) all target animals need to be put at risk by the methods being used, (2) deer populations must be killed faster than their rate of increase at all densities, (3) the risk of recolonisation must be zero (or at least manageable), (4) socioeconomic factors must be conducive to meeting the critical rules, (5) where the benefits of management can be achieved without eradication, discounted future benefits should favour the one-off costs of eradication over the ongoing costs of sustained control, and (6) survivors should be detectable, and once detected, they should be killed before the population can increase. Of these, rules 1–3 and arguably 4 are regarded as crucial to the success of eradication efforts, whereas rules 5–6 are considered desirable.

There are numerous factors that violate the strategic rules for eradication of wild deer from Northland. Perhaps most importantly, the risk of recolonisation is not zero and it is probably not sufficiently manageable to enable successful eradication of all wild deer from Northland, i.e. at a regional scale (also see Fraser et al. 2003). Although waning, deer farming remains permissible in some parts of Northland and farmed deer periodically escape (despite ongoing fence inspections and maintenance) and contribute to reinvasion risk (Gardiner 2015). Deer, particularly sika deer (*Cervus nippon*) and fallow deer (*Dama dama*), are being illegally liberated often enough to thwart eradication programmes (Fraser et al. 2000; Gardiner 2015). Not only does this violate strategic rule number three, but it also violates rule number one, all target animals need to be put at risk by the methods being used, because some private landowners are denying access to professional hunters to kill liberated deer at release sites and their surrounds. Unless this can be addressed through appropriate legislative and regulatory frameworks, eradication (at a site scale and hence a regional scale) will not be feasible. Finally, because Northland borders a region (Auckland) that has established populations of wild deer (Latham et al. 2012a) the threat of invasion via natural dispersal into suitable habitat in the south of Northland Region is not zero. It should be noted, however, that natural dispersal is considered less of a threat than farm escapes and illegal liberations (Fraser et al. 2000), particularly given that management authorities in Auckland Region are attempting to eliminate potentially threatening populations (other than the South Kaipara fallow deer herd, which is arguably constrained by geography) (Latham et al. 2012a).

Precedence

The feasibility of eradication can also be judged by precedence – has the target species been successfully eradicated under similar circumstances? To my knowledge, attempts (ongoing since 2001) to eliminate isolated low density populations of red deer (*Cervus elaphus*) and fallow deer in Auckland Region have not been successful (Wilson 2012; M. Mitchell, Auckland Council, pers. comm.). These populations are closest geographically to Northland Region and, although suitable deer habitat in Auckland Region is patchier, habitat characteristics and objectives of collaborating management agencies are broadly similar to Northland (McKenzie et al. 2004; Wilson 2012; Latham et al. 2012a). An inability to eliminate unwanted deer populations from Auckland Region probably stems from (at least) some of the six strategic rules for eradication being violated, e.g. deer populations are probably not being killed faster than their rate of increase (at all densities), the risk of recolonisation is not zero (though it may be manageable), and socioeconomic factors are not conducive to meeting the critical rules (such as decreases in annual funding; Wilson 2012). However, control operations in Auckland Region appear to have kept wild deer at moderately low numbers and protected two key assets, the Waitakere and Hunua ranges, from deer incursions (Wilson 2012). In conclusion, the theoretical and logistical constraints to eradication (at a regional scale) faced by the two regions are broadly comparable.

Red deer have been removed from Anchor Island (1130 ha) and (with the exception of one male) Secretary Island (8100 ha), Fiordland (Crouchley et al. 2011; N. MacDonald, Department of Conservation, unpubl. data). Although the risk of reinvasion is not zero – deer can swim to these islands from the mainland (Crouchley et al. 2011) – the six strategic rules for eradication were met (assuming that reinvasion risk was manageable). Notably, funding necessary to kill all deer was estimated (Nugent & Arienti-Latham 2012) and secured for the duration of the programme, and potential social problems, such as cross-boundary landowner issues, were not a constraint because the islands are part of the estate managed by the Department of Conservation. Further, all deer were put at risk by the methods being used and they were killed faster than their rate of increase. Despite this, eradication (or extirpation of resident deer; Edge et al. 2011) took much longer than anticipated, e.g. it was estimated at 4 years for Secretary Island (Crouchley et al. 2007; Nugent & Arienti-Latham 2012), but it actually took about 9 years to achieve (N. MacDonald, Department of Conservation, unpubl. data).

Deer removal during the Anchor Island and Secretary Island operations followed a typical pattern for wild ungulate eradication programmes, with the greatest reduction in deer density being made during the 'knockdown' phase (Crouchley et al. 2011; Nugent & Arienti-Latham 2012). It is critical to remove as many deer as possible at each encounter during this phase so that survivors do not have the opportunity to learn to avoid controllers. Once the population has been reduced to very low levels, a ‘mop-up’ phase is required to remove any survivors. For example, an estimated eight deer survived the 2-year knockdown phase on Secretary Island and it took about 7 years to mop-up these survivors (Nugent & Arienti-Latham 2012; N. MacDonald, Department of Conservation, unpubl. data). Kills per unit effort generally declined throughout the campaign (Crouchley et al. 2011) and costs per kill were substantially higher (>$4000) at low deer density during the mop-up phase compared to higher densities during the knockdown phase (<$1000) (Nugent & Arienti-Latham 2012). Once all survivors are removed, a ‘validation’ phase is required to confirm with some degree of confidence that the target population has been eradicated (see 3.1.3 Surveillance and monitoring). Finally, if reinvasion is possible, it must be manageable, and this necessitates a fourth phase of surveillance and ‘border control’ or ‘quarantine’. It is important to highlight that there must be sufficient funding to complete all of these phases of an eradication operation. If there is not, the fourth strategic rule for eradication, socioeconomic factors must be conducive to meeting the critical rules (i.e. sufficient funding is in place for the duration of the operation), is not met and eradication of the target population will be unlikely to succeed.

3.1.2 Strategic sustained control of wild deer

Strategic rule for eradication number five states where the benefits of management can be achieved without eradication, discounted future benefits should favour the one-off costs of eradication over the ongoing costs of sustained control. Although ‘one-off’ costs for ungulate eradication may continue for a number of years (e.g. Anchor Island and Secretary Island), they are considered preferable to the (initially) high costs of reducing the targeted pest to a threshold where their impact is deemed tolerable and then the in perpetuity costs of keeping them at or below that threshold. What does this mean for the management of wild deer in Northland? It means that although the six strategic rules for eradication are unlikely to be met at a regional scale, elimination of isolated deer populations (i.e. at the site scale) should be preferred over sustained control of those populations (so long as they meet the strategic rules for eradication). However, the reinvasion risk will not be zero, and thus it must be managed using the fourth phase of an eradication operation, i.e. surveillance and control to prevent reinvasion. This strategy has already been used successfully in Northland (Fraser et al. 2003), and should continue to be used on existing populations and future incursions that meet the criteria for site-level eradication (local elimination). For populations that do not meet these criteria, sustained control is the best option. Given that the management objective for Northland is to keep the region (insofar as is possible) deer-free (McKenzie et al. 2004), the most tolerable target density (in the absence of elimination) is one where it is difficult to detect them because of their scarcity. If it is not possible to achieve this very low density, some higher, but tolerable target density must be identified (preferably based on known density-impact relationships) (Norbury et al. 2015).

As an example, the Russell sika deer population does not (at least currently) meet the required criteria for successful eradication. There is a high chance of reinvasion due to further illegal liberations and some deer cannot be put at risk of being killed because professional hunters are being denied access onto some of the private land where the deer live. This suggests that (at least currently) sustained control is the best strategic option. Assuming six individuals (3 male and 3 female) remain in that forest, an intrinsic rate of increase of 0.33 (i.e. a doubling time of a little over 2 years) for unhunted sika deer (Fraser 2005a), and restricted access results in an inability to target these deer for 5 successive years, the starting population is estimated to increase to 31 individuals in those 5 years (8, 12, 16, 22, and 31 in years 1 to 5, respectively). If this herd is topped up by further illegal liberations, then clearly these estimated population increases will be even greater. This highlights the need for (preferably) annual sustained control, buy-in from local landowners and communities, appropriate legislative and regulatory frameworks to be in place if land access is denied, and for those that continue to illegally liberate deer, heavy punishment. Successful control is rarely limited by suitable control technologies (Parkes 1993; see 3.2.1 Control solutions), but rather is most often limited by socioeconomic constraints that are not adequately managed before a project is started.

3.1.3 Surveillance and monitoring

Irrespective of whether eradication or sustained control is deemed appropriate for a target population, some form of surveillance and monitoring must be incorporated into management plans. For example, it is critical to identify an incursion as quickly as possible so that it can be dealt with promptly (e.g. Gherardi & Angiolini 2008). Similarly, it is necessary to know with a high degree of certainty whether survivors remain following an eradication attempt. Ideally, the extent of the area occupied by the target population should be known before control starts so that controllers know where hunting effort should be focused and so that planners can budget accordingly. All of these aspects require detecting deer at very low numbers. Although there are a number of methods for detecting deer, including some new technologies that show promise (see 3.2.2 Surveillance solutions), it is difficult to detect very low numbers of invaders or survivors and to delimit the extent of their population (Gormley et al. 2011). Often these factors become clearer following efforts to locate and kill the animals and as anecdotal reports of their whereabouts become available.

At very low densities of deer (as they will be in the Northland scenario), using methods such as camera traps or formal faecal pellet surveys (as opposed to random observations) for surveillance and monitoring will result in data consisting primarily of ‘no detections’. Do these zeros reflect true absences or an inability to detect the few animals present because of insufficient sampling effort? Appropriate sampling intensity is critical, because managers want to avoid situations where deer are really present but are not detected or eradication is falsely claimed (Fraser et al. 2003). For example, Gormley et al. (2011) assessed the detection probabilities for two devices (three faecal pellet transects and two camera traps) set up to detect sambar deer (*Rusa unicolor*) in an area known to have sambar deer in Victoria, Australia. They reported that faecal pellet surveys and camera traps detected the presence of deer with probabilities of 0.74 and 0.51, respectively. This means that there was a c. 75% chance of detecting a sambar deer given they were present using faecal pellet surveys and a c. 50% chance of detecting a deer using camera traps. If all methods (including random observations of deer sign) were combined, the detection probability was high (97%); however, because many deer were present at their study location, this is a best-case scenario. Deploying sufficient detection devices to have confidence that zeros truly reflect no deer rather than an inability to detect them is difficult and expensive and must be balanced against the costs of being wrong (Fraser et al. 2003).

Monitoring and detection devices need not be deployed as the primary method of identifying new incursions or locations of survivors. First, as mentioned above, using a number of methods usually results in a higher probability of detection (Gormley et al. 2011) and this is critical, given the very low numbers of deer being targeted in Northland. Second, they can be used strategically in conjunction with Northland's early reporting system of new deer populations (Fraser et al. 2003) and informal monitoring (i.e. opportunistic sightings of deer or their sign) done during control work, to provide fine-scale, secondary information about habitat use, behaviour, group sizes, and so on. Essentially, this second point relates to the need to use a stratified design to survey an area, with more sampling effort/devices located in areas known or suspected to have most deer. In this instance, information from the early reporting system and informal monitoring would be used to help stratify the area being surveyed. Using this approach might shorten the duration of a mop-up phase during an attempt to eliminate an isolated population, or assist in maintaining the lowest achievable density for populations that do not meet the criteria for eradication.

The management objective in Northland is to keep the region, insofar as is possible, deer free. This means that there will probably be little need for outcome monitoring to demonstrate that deer control has reduced their unwanted impacts. That is, the impacts caused by exceedingly low numbers of deer will probably not be at levels that are detectable before or after their removal (other than qualitatively, i.e. deer tracks were seen before control, but not after). Similarly, it will be difficult to disentangle their unwanted impacts from those of sympatric introduced mammalian herbivores, such as feral goats (*Capra hircus*). Thus, the focus of monitoring wild deer in Northland should be on early detection, a robust estimate of the number of invaders/survivors and how these trend in response to control actions, and validation (if elimination/eradication is the goal).

3.2 Tactical options for managing wild deer

3.2.1 Control solutions

A number of methods are available for controlling wild deer in Northland; however, many of these are unlikely to be viable control methods in this region given current management objectives for wild deer and the socio-physical characteristics of the region. I briefly discuss some common or topical methods that I view as unsuitable for deer control in this region, but focus on those methods that have been used successfully in similar situations, i.e. those for which there is precedence.

Non-lethal control

There are a number of non-lethal methods that can be used to control deer under some situations. These are often preferred by the public because of higher animal welfare. I do not spend much time discussing these because they are unlikely to be economically or logistically feasible for widespread use in Northland. Further, they will probably not be able to achieve local elimination of herds that meet the criteria for removal or reduction to the lowest achievable density for all other herds.

Fencing (exclusion zones) and scare devices and repellents do not reduce deer numbers, but rather they move the animals and their unwanted impacts elsewhere. Further, scare devices and repellents are usually short-term solutions and they can be annoying to humans (Bomford & O'Brien 1990). I similarly do not consider live capture or fertility control viable options for management in Northland. The most common methods of capturing deer alive include: cage traps, rocket or cannon nets, drop nets, drive nets, corral traps/walk-in enclosures, remote chemical immobilisation, and net-gunning, darting or bulldogging (the shooter jumping onto a deer and wrestling it to the ground) from a helicopter (Rongstad & McCabe 1984). These methods were not designed for broad-scale control or elimination of deer populations and would be particularly challenging for those populations that occur in dense vegetation, e.g. sika deer in Russell Forest. Live capture also has specific welfare issues related to animal capture and housing, even if animals are kept in captivity for only a short period of time. A review assessing the efficacy of fertility control or contraception for wild deer, using methods such as surgical sterilisation, hormone implants and vaccination, reported that substantial initial effort and funding is generally required to reduce population growth, if fertility control is the sole wildlife management method (Massei & Cowan 2014). There have been a few studies that have demonstrated that fertility control, particularly of peri-urban deer or isolated populations, can be successfully used to limit population growth and reduce human-wildlife conflicts (see review and references therein by Massei & Cowan 2014). However, I believe this approach has little utility for wild deer management in Northland Region because it is expensive and logistically difficult with comparatively inaccessible deer, there is a probable lack of experienced and qualified staff to administer treatments, and there is a need to treat a large proportion of the female population (>90%) for the method to significantly reduce populations.

Lethal control

I believe that lethal control methods are far more suitable for control of wild deer populations in Northland. To date, deer control in this region has been done exclusively by professional, fulltime ground hunters (usually with trained dogs) that specialise in pest control (Gardiner 2015). These hunters are also responsible for liaising with deer farmers to ensure deer fences are of high standard and communicating with them to ensure quick solutions should an escape occur (Fraser et al. 2003). Recreational hunters are an alternative to professional hunters. The advantages of using recreational hunters are that they are cheap and their use can advance wider stakeholder engagement between government land management agencies and the hunters (Parkes & Forsyth 2011). However, there are notable disadvantages to using recreational hunters, particularly when the management objectives are elimination of isolated populations or control to very low densities (Parkes & Nugent 2013). This is because the rewards for recreational hunters (the number of animals available to be shot and thus the hunting experience) are low and hunting in areas with higher animal densities (higher rewards) can usually be found elsewhere. Recreational hunters also struggle to achieve results in a short time frame or in remote or difficult terrain far from a point of access for vehicles (Nugent 1988; Fraser 2000; Simard et al. 2013). Recreational hunters have access to many areas where wild deer populations occur in Northland and they do shoot deer, e.g. two sika deer (one stag and one hind) were shot in the Whakawhiti Stream, Russell Forest, by recreational hunters during the 2014 rut (Gardiner 2015). However, because recreational hunting is largely opportunistic in Northland, I do not believe that they can be used as part of formal deer control (at least in most situations). Further, they also pose a health and safety risk to the professional deer response team.

The use of professional hunters for deer control/eradication is the approach taken by most land management agencies internationally (e.g. Crouchley et al. 2007; Ramsey et al. 2009) and I recommend that it should be the primary method of controlling wild deer in Northland. Specialised or interested staff within land management agencies can also be effective at controlling deer. The advantage of using agency staff is that they are usually familiar with the area being controlled and some may have the skills and drive to achieve eradication or targeted control to a specified level. The primary disadvantage is that unless staff are dedicated to the task fulltime, their approach to hunting may not be done in a systematic way – rather their efforts may be more-or-less done out of interest and when they get spare time. Control efforts then become sporadic partial control and this will probably not be adequate for elimination of isolated herds or control to very low density. Private contractors have advantages over agency staff in that the former can be deployed under performance-based contracts while in-house hunters generally only have input-based incentives. Performance-based contracts have worked effectively for eradication programmes (e.g. Morrison et al. 2007), but contracts can set out milestones for sustained control, such as reducing deer numbers to some estimated acceptable density/relative abundance. The contractor provides a fixed price to achieve the agreed upon milestones and final payment of the contract is made only when these have been achieved. Critical to this approach is an independent evaluation of whether or not the defined outcome has been achieved (Ramsey et al. 2009). What does this narrative mean for Northland? The professional deer response team in Northland initially followed an agency (Department of Conservation) staff model, before transitioning to a private contractor model (Gardiner 2015), both of which were largely motivated by input-based incentives. As this team nears retirement, it is necessary to ensure that a succession plan is put in place and to decide whether a performance-based contract is suitable for emerging contractors and, if so, what form that should take. Given that the response team also conducts other activities related to deer management, such as deer farm inspections, some combination of daily or hourly rate and performance-based contract may be most appropriate.

Aerial shooting from helicopters can be a highly effective method for controlling populations of wild deer in open or semi-open habitats (e.g. Nugent & Choquenot 2004). It may not be feasible to use aerial shooting in densely forested habitats, such as the core forested area of Russell Forest; however, it will likely have utility in more patchy habitats, such as some of the areas surrounding Russell Forest. I recommend that, in addition to ground-shooting, Northland's professional deer response team should use aerial shooting of wild deer in suitable habitat. Thermal infrared imaging – technology that is able to detect the body heat of warm-blooded animals (e.g. Gill et al. 1997) – could be incorporated into ground and aerial control of wild deer in areas where it can be safely used and is predicted to increase kill rates. Because thermal infrared imaging cannot reliably detect deer (or other animals) through forest canopy (Gill et al. 1997), aerial use is likely to be most efficacious in open or scrubby habitat, such as on farmland surrounding forested areas with known deer populations or forestry blocks with plenty of open habitat. Fraser et al. (2003) have previously recommended this as a potential method to detect deer in some areas within Northland (see 3.2.2 Surveillance solutions), but, given the advent of new thermal imaging rifle scopes, I suggest extending the use of this technology to include control of wild deer. I also discuss below (3.2.2 Surveillance solutions) other new technologies or relatively untried solutions that may assist Northland's professional deer response team to control wild deer in the region.

Aerial poisoning can kill large numbers of deer, particularly in aerial baiting operations for brushtail possum (*Trichosurus vulpecula*) or European rabbit (*Oryctolagus cuniculus*) control in New Zealand (Fraser et al. 2003; Forsyth et al. 2013). However, the proportion of wild deer killed by toxic baits sown from the air can be variable across populations (Veltman & Parkes 2002). Further, there are a number of disadvantages associated with using this method for wild deer. Some toxins pose primary and secondary poisoning risks to non-target species (McIlroy 1982a, b). Public opposition to poisoning can be high – opposition arises primarily from real or perceived risks to non-target species, animal welfare concerns, and the perception that other control methods are more effective or appropriate (Green & Rohan 2012; Latham et al. 2012b). Use of toxins can have significant permitting constraints near areas of human habitation or high recreational use. I discount aerial poisoning as an option for controlling wild deer in Northland because it is not currently registered for use on deer in New Zealand and, in any case, it might face staunch public opposition and end up compromising buy-in from local communities and other stakeholders for deer control in Northland. Foliage gel-bait poisoning has been successfully used on deer in Stewart Island and in the central North Island (Nugent 1990; Sweetapple 1995, 1997). It has the advantage over aerial baiting that baits and toxins can be removed, although doing so adds cost. Veltman and Parkes (2002) reviewed studies that had used this method and concluded that foliage gel-bait poisoning has generally been successful against deer in New Zealand, although it should be noted that it may have limited efficacy if preferred foods are abundant (i.e. the foliage used as bait may not be especially attractive to well-fed deer) (Crouchley et al. 2011). However, I do not recommend it as a control option because of high secondary poisoning risks to dogs and (at least) some public opposition to its use.

3.2.2 Surveillance solutions

It is difficult for a comparatively small deer response team to be able to adequately survey an area the size of Northland Region to quickly detect deer that have escaped from a farm or been illegally liberated. If farmers are unable to recapture escapees themselves, they can take advantage of the successful working relationship that has developed between farmers and the deer response team, in which farmers are encouraged to quickly notify the team about an escape and the team then provides the free service of recapturing or killing escapees (Fraser et al. 2003; Gardiner 2015). If not reported by the farmer, escapes and illegal liberations of deer are generally first noticed by other members of the rural community (Fraser et al. 2003). In Northland, the Department of Conservation has an early reporting system (Find Deer Hotline – 0800 346 333) to gather information from the public (Gardiner 2015). Reports deemed sufficiently reliable are promptly followed up and investigated by the response team (Fraser et al. 2003; Gardiner 2015). For populations of wild deer that are undergoing a control or eradication programme, information (data) about very low numbers of survivors and their locations often becomes clearer following the efforts of the deer response team to locate and kill those animals. To date, this system has worked effectively in Northland and it should continue to form the backbone of surveillance and monitoring of wild deer in the region. In particular, I emphasise the importance of obtaining/maintaining buy-in from the local community and other stakeholders through informal farm visits (i.e. the ‘cuppa tea’ approach). However, there are a number of other methods that might complement the current approach to surveillance and monitoring – potentially improving current detection and control methodologies – and I give details of these below. I do not provide a thorough review of all monitoring methods that have been used for wild ungulates (including in New Zealand), but rather direct readers to Forsyth (2005) and the reviews in Latham et al. (2012a, b).

Camera traps

Infrared or white-light flash cameras are widely used in ecology to remotely collect data on animal presence, activity, and behaviour, and to produce indices of population abundance or estimate population size (e.g. Cutler & Swann 1999). As previously mentioned, using camera traps for formal monitoring of areas containing very low numbers of deer will result in data consisting primarily of ‘no detections’. The sampling effort (number of cameras) that would be needed to have confidence that zeros truly reflected no invaders (for an incursion) or no survivors (following eradication) would probably be prohibitive (a large number of cameras and thus high costs). Consequently, I do not view camera traps as a method that has high utility for formal broad-scale surveillance or monitoring of low numbers of wild deer in Northland. However, as random observations of deer (or their sign) become increasingly available throughout a control or eradication programme, camera traps could be deployed at sites of interest identified by the response team to provide fine-scale data about seasonal habitat use, movement corridors, confirming group sizes and sexes, and so on. Information obtained from camera traps might assist the response team to increase their kill rates by improving their knowledge about when and where to target deer. Another possible advantage of this method is that camera images can be obtained remotely from camera traps (at least for some makes and models) in ‘real-time’ using the cellular network (if it is available in the area being surveyed). This may circumvent the need to regularly check and service camera traps. Further, images downloaded in real-time might indicate optimal times to target survivors without the need for a physical boots-on-ground survey of the area, e.g. when surviving sika deer in Russell Forest are in an area that can be legally hunted by the deer response team (as opposed to being on private property to which access has been denied). A disadvantage of camera traps is that the hardware is prone to being stolen or vandalised.

Accoustic monitoring systems

These devices are becoming increasingly prevalent and have the potential to provide data useful for a variety of behavioural or ecological research and management questions (Wall et al. 2014). For example, they can provide ‘real-time’ directional tracking of animal sounds and gunshot detection (useful for anti-poaching programmes), both of which have immediate application for wildlife management purposes (Wall et al. 2014). Acoustic monitoring devices could be deployed alone or with camera traps to maximise information about deer presence and behaviour. Because they are designed to monitor animal sounds, some thought would need to be given to when they should be deployed, e.g. for sika deer, it might be most useful to deploy them during the rut, when this species is most vocal (Fraser 2005b). As with camera traps, acoustic monitoring devices are likely to be stolen or vandalised if they are seen by some members of the public.

Thermal infrared imaging

Thermal imagers have been used for ground- (e.g. Gill et al. 1997) and aerial-monitoring (e.g. Havens & Sharp 1998) of wildlife for >20 years, although technological improvements have been substantial since their inception. Although confidence in estimates of deer abundance using thermal imagers for (for example) distance sampling are increasing (Wäber & Dolman 2015), I see little or no utility in them for wild deer in Northland (because deer numbers are exceedingly low). Rather, as suggested by Fraser et al. (2003), I see their use being greatest for surveillance and detection of wild deer. They cannot detect deer through dense forest canopy (i.e. as would be needed for aerial surveys) and it would be too arduous and costly to use them to survey entire medium- to large-sized forests with dense canopy from the ground, and thus I do not recommend their use in dense forests (other than where they might be useful for improving ground control). However, thermal imagers will likely be useful for detecting wild deer that emerge from dense forests to feed on adjacent farmland during late evening to early morning and in semi-open shrub and forested habitats. Surveillance of these areas could be done from the ground or the air depending upon accessibility.

Judas deer

Using 'Judas' animals to track down and kill survivors of eradication or control operations is a commonly used approach for feral goats (e.g. Parkes 1993). The use of Judas animals could just as easily have been discussed under 3.2.1 Control solutions, but I have chosen to discuss it here because it initially increases the probability of detecting survivors. The method uses one or more radio-marked individuals released into an area where conspecifics surviving initial knockdown programmes are suspected or known to be. The aim is that these individuals will seek out and group up with survivors (even if they are not related), allowing controllers to more readily locate and kill (mop-up) survivors using either ground or aerial methods. Very high frequency (VHF) or global positioning system (GPS; preferably with a VHF beacon) collars can be deployed on Judas animals. The advantage of GPS collars is that additional information about fine-scale spatiotemporal habitat use, range extent, and behaviour can be obtained (Latham et al. 2015a), potentially improving future control efforts. The disadvantage of GPS collars is that they are expensive compared to VHF (Latham et al. 2015a), and if the animal wearing the collar is shot by recreational hunters, the collar may be stolen or purposely destroyed.

To my knowledge, the Judas method has been trialled only on red deer in the Murchison Mountains and Anchor and Secretary Islands, South Island, and results of those trials suggested that it might be a key tool for mop-up and maintenance phases of deer eradication (Crouchley et al. 2007, 2011). The Judas method has also been recommended as having possible utility for deer control or eradication in Northland Region (Fraser et al. 2003) and Auckland Region (Latham et al. 2012a), but thus far has not been used in those regions. The method is likely to have greatest utility for species that are highly social because they will be more likely to seek out conspecifics than solitary or 'barely social species' such as sambar deer (Mattioli 2011). For example, the Judas approach might be useful for red deer as they tend to aggregate into matrilineal kin or stag groups (Nugent & Fraser 2005) and fallow deer because they tend to be gregarious (Nugent & Asher 2005). Latham et al. (2012a) suggested that sterilised juvenile females are probably the best Judas candidates for social species because they will be less likely to make long distance dispersals compared with males, or to remain independent of other groups, like mature females. These authors add that targeting surviving females will have a greater effect on population reduction than targeting males.

Sika deer in New Zealand and elsewhere within their native and introduced ranges are considered a moderately social species showing (sometimes strong) sexual segregation (Fraser 2005b; Mattioli 2011; Latham et al. 2015b). In New Zealand, intensive recreational and aerial hunting has markedly reduced historical larger mixed groups of sika deer (Davidson 1973) and most now live in small groups or alone (Fraser 2005b). Thus it is debateable whether deploying Judas female sika deer would be as useful as it has proven to be on more social species (Parkes 1993; Crouchley et al. 2007, 2011). However, sika deer stags use a number of behavioural strategies to acquire mating opportunities during the rut that result in males and females being found together more often than at other times of the year (Bartos et al. 1998; Fraser 2005b). It may be possible to utilise breeding behaviour of radio-marked male sika deer to betray the locations of females to professional hunters during the rut. An advantage of using one or more males as the Judas animals (c.f. females) is that releasing them will not increase reproductive potential within the target population (assuming that survivors already comprise at least one male to fertilise females), although, as stated above, females can be sterilised prior to release (Latham et al. 2012a). A potential disadvantage of using male sika deer as Judas animals is that they are prone to making long distance dispersals (Fraser 2005b). Survivors detected with Judas deer in Northland could be targeted using ground and aerial methods, the appropriateness of which will probably be dependent on forest canopy cover, e.g. sika deer in Russell Forest are likely best targeted using ground-based control methods.

3.3 Knowledge gaps

There are key pieces of information that may improve the management of wild deer in Northland Region. Investigating these is beyond the scope of this report; however, I highlight below some of those that I view as potentially important. It is important to note that collecting new information/data – whether it be via desk-top reviews, statistical or simulation modelling or primary research – is expensive, sometimes very expensive (in the context of an annual budget for a deer control programme). Strategic rule for eradication number four states that socioeconomic factors must be conducive to meeting the critical rules. Thus, before money is directed at research, there should be agreement that the research has high potential to improve current control methodologies. Similarly, the funding for new research should not be taken from the annual budget for elimination of isolated populations (unless they have all been eliminated from Northland), control efforts to keep other populations at the lowest achievable density or surveillance. If it is, then control efforts are prone to failure.

3.3.1 Relative risks of deer species

Having a better understanding of the relative risks that different deer species pose to assets in Northland and differences in their manageability might help prioritisation if deer numbers were to increase in Northland because, for example, annual funding for their control was substantially reduced. Much of this information is already available, e.g. see reviews by Fraser (2005b; sika deer), Nugent and Fraser (2005; red deer), and Nugent and Asher (2005; fallow deer) from which information can be gleaned about the relative impacts to native plants, rates of increase, and relative risks posed by differences in dispersal. Ideally, data from Northland would be used to parameterise predictive models assessing rates of increase and rates of spread for each species; however, the cost of this is likely to be prohibitive. As a substitute, a desk-top review and a simple simulation model (parameterised using existing data not specific to Northland) may provide sufficient information about the relative risks posed by each species (assuming different farm escape and illegal liberation scenarios), but at much lower cost. This has already been done for sika deer (Fraser 2005a) and an update of this work is unlikely to result in large changes of the general conclusions in that report.

3.3.2 DNA genotyping

DNA genotyping might be useful to determine whether deer detected at a site known to have had a wild population (thought since to have been eliminated) represent survivors of the original population or a new incursion. A similar approach was used for red deer on Secretary Island and Murchison Mountains, Fiordland, with mixed success (Crouchley et al. 2011). This study collected hair samples from ground-shot animals and obtained useful genotypes from 72 adult females and 13 calves. However, they found little variation between animals using 14 genetic markers and there were a number of instances in which the sets of alleles for a calf matched those for two or more adult females. This means that those calves could have been assigned to more than one potential mother, rendering the approach invalid (Crouchley et al. 2011). Using a much larger set of genetic markers may solve this problem, but this was not explored by Crouchley et al. (2011) because of cost. Thus, the utility of this method for deer in Northland would depend upon genetic variability within the population using a relatively small number of genetic markers or current cost of DNA genotyping using a large number of markers. Using this method to identify the potential source of an illegal liberation is likely to be prohibitively expensive because it would require DNA samples from the entire sika deer range.

3.3.3 Data collection, management and analysis

Although slightly tangential to knowledge gaps, it is worth highlighting various aspects relating to data requirements. Summary statistics (quantitative and qualitative) are updated annually in the wild deer in Northland annual reports (Gardiner 2015). These reports provide an annual summary of the programme since its inception in 1997/1998, locations and bovine tuberculosis status for wild deer killed, farm escapes recovered or killed, and deer farms depopulated. This information should continue to be collected. Although outside the scope of this report, management agencies might want to consider reviewing current data collection, management and analysis methods to determine whether additional information needs to be collected and if data entry, management and analysis can be improved. Similarly, as existing personnel near retirement, it is essential that a succession plan is put into place for data collection, management and analysis, and to decide which management agency will adopt this role (or how it will be partitioned). Further, depending upon (particularly) which tactical options are chosen for control or management of deer in Northland Region, additional data collection will be required. This may include collecting GPS track files from ground hunters; flight logs from aircraft during surveillance or control operations; GPS locations of deer seen and killed for both ground and aerial operations; DNA samples (hair and/or tissue); and locations of ground and aerial monitored, radio-marked animals (and metadata). Similarly, if camera traps, acoustic monitoring systems or GPS collars are used, a large amount of data will need to be managed and analysed. However, before a data collection, management and analysis plan can be put in place, it is necessary to know (1) what surveillance and control methods will be used and what hardware will deployed; (2) what question/s relating to improving surveillance and control will be addressed; and (3) what funding is available to do this?

4 Recommendations

- Although eradication of wild deer from Northland at a regional scale is unlikely to be achieved unless issues related to escapes from deer farms and land access for professional hunters are resolved, populations that meet the requirements for eradication should be targeted for elimination. For all other populations, the management objective should be the lowest achievable density.
- The early reporting system (Find Deer Hotline – 0800 346 333) should continue to be used to gather information from the public about sightings of wild deer or escaped farm deer. The Northland deer response team should continue to prioritise informal farm visits to obtain/maintain buy-in from deer farmers, and help improve deer husbandry and manage deer escapes.
- The use of professional fulltime ground hunters (using trained dogs, as required) should continue to be the primary method of removing wild deer and escaped farm deer (unless recaptured) from Northland Region. A succession plan should be established to ensure future capability as the current deer response team nears retirement age. Some combination of performance-based contract and hourly rate might be most appropriate for professional hunter services.
- Northland's professional deer response team should consider using aerial shooting of wild deer from a helicopter where there is suitable habitat, particularly pasture–forest margins, scrub, and native and plantation forests with canopy that is sufficiently open to allow deer to be seen and shot.
- The use of thermal infrared imaging technology should continue to be incorporated into deer management in the region. This may include both ground- and aerial-based use of equipment and will have application for both surveillance and control.
- The strategic use of camera traps, acoustic monitoring devices, and Judas deer will provide fine-scale data about seasonal habitat use, movement corridors, and confirming group sizes and sexes, and thus may assist the response team to increase their kill rates by improving their knowledge about when and where to target deer.
- If a performance-based contract model is adopted for professional hunters, a protocol will need to be developed to independently evaluate whether or not a defined outcome has been achieved.
- If new control strategies and methods are adopted, it may be necessary to refine data collection, management, and analysis processes. The above successional plan should ensure that future capability includes rigorous training in data collection and management by professional hunters, as well as appropriate institutional data management and analysis.

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